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Regional Crop Yield Response for U.S. Grains

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Abstract

Crop yields in all major production regions increase substantially in response to three major long-term stimuli: improved varieties, improved farming techniques, and more fertilizer. Short-term factors affecting yields include soil moisture, temperature and precipitation during the critical months of crop production, and acreage reduction programs. This report examines how the acreage reduction programs affect crop yields, what determines yields, and how to project crop yields. Per acre yields of wheat, corn, and rice by major region are projected to 1990.

Keywords: Crop yields, grains, soil moisture, temperature, precipitation, acreage reduction programs, yield projections.

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Summary

Crop yields in all major production regions increase substantially in response to three major long-term stimuli: improved varieties, improved farming techniques, and more fertilizer. Short-term factors affecting yields include soil moisture, temperature and precipitation during the critical months of crop production, and acreage reduction programs. This report examines how the acreage reduction programs affect crop yields, what determines yields, and how to project crop yields.

Yields will probably continue upward through 1990 barring unusual weather conditions. Effects of soil moisture, temperature, and precipitation in critical months vary among regions and grains.

The adoption of short-strawed and semidwarf varieties has helped boost wheat production in all regions studied. Corn production yields climbed from 25 bushels per acre in the 1930's to 119 bushels in 1986 because of high-yielding varieties. New varieties of rice developed since 1983 have led to record yields in the South and in California.

Farmers have also raised yields by combining higher seeding applications with better control of weeds, insects, and diseases and stepped-up fertilizer use. For example, in 1985, corn yields increased 0.2 percent for each 1-percent increase in nitrogen applied under normal rainfall.

Recent acreage reduction programs (ARP) have actually improved production efficiency and have raised yields because participating farmers tend to remove marginal, low-yielding land from production. Thus, a percentage reduction in acreage is not matched by a corresponding decline in production. National average yields for major grains increased in 1986 under ARP compared with no ARP: wheat, up 6.6 percent, 2.5 bushels more an acre; rice, 10.1 percent, 500 pounds; and corn, 5 percent, 5.7 bushels higher. The program slippage effects could be greater because farmers may devote more time and inputs to fewer acres.

The authors forecast the following regional yields (assuming normal weather and no severe plant disease or fungus):

	1987	1988	1989	1990
		Wheat (bushels)		
Northern Plains	38.4	39.7	40.8	41.5
Southern Plains	30.4	30.7	31.1	31.4
Mountain region	37.0	37.5	38.1	38.6
Pacific region	66.6	67.9	69.3	70.6
Corn Belt	44.7	45.2	45.9	46.4
Lake States	41.2	41.9	42.5	43.2
United States	40.0	40.7	41.6	42.1
		Corn (bushels)		
Corn Belt	131.0	133.7	136.2	138.1
Northern Plains	111.2	113.1	115.0	116.9
Lake States	118.5	121.8	125.2	128.0
United States	124.3	127.0	129.6	131.7
		Rice (pounds)		
Arkansas	6,028	6,164	6,286	6,329
Louisiana	4,453	4,508	4,545	4,553
California	7,814	8,009	8,203	8,397
Texas	5,961	5,937	5,982	5,995
Mississippi	4,660	4,701	4,717	4,719
United States	5,890	6,007	6,105	6,158

Regional Crop Yield Response for U.S. Grains

Mark S. Ash
William Lin*

Introduction

Yield variability triggers most of the changes associated with producing U.S. grains. By projecting production through timely crop yield estimates, analysts can help buyers and sellers adjust marketing strategies. Better forecasts would enable researchers and policymakers to assess more accurately the budget outlays for Government farm programs.

The main purpose of this study is to model the yield response for major U.S. food and feed grains, including wheat, rice, corn, sorghum, barley, and oats. We determined separate estimates for winter wheat, spring wheat, and all wheat. Crop yield response for each grain is estimated for major U.S. Department of Agriculture (USDA) farm production regions (fig. 1).

The equations to be presented are not intended to substitute for the use of current methods of crop measurement, such as farmer surveys, satellite imagery, and objective plot samples. We attempt to shorten the time lag (at a minimal cost) between observed weather conditions and official estimates of crop supplies.

Methodology

Hazell (*12*) decomposed the change in average production for the major U.S. grains into changes in mean yields, mean acreage, an interaction effect, and change in covariability of yield and area.[1] During 1950-80, mean yield changes accounted for 93, 86, 66, 84, and 46 percent of the change in average production of corn, winter wheat, sorghum, spring wheat, and rice. He also found that changes in yield variances and area-yield covariances contributed most to total grain production variability.

Research on crop-yield response has proven useful to economic analyses. Before the critical months when temperature and precipitation significantly affect grain yields, estimated crop-yield response could be used to project the size of a grain crop, assuming normal weather and a knowledge of farmers' planting intentions.[2] Information about soil moisture, temperature, precipitation, and planted acreage in the critical months can then be factored into crop-yield projections. Projected crop production can then be updated several times as the growing season progresses.

Estimated crop-yield response is useful in policy analysis. When farmers remove marginal, lower yielding land from crop production to comply with acreage reduction programs (ARP), average crop yield on remaining acres tends to increase for most grains, partly undercutting the program effort to control production. A change in farm programs, however, most likely would affect commodity prices and the use of inputs. A related policy issue is: how would the change in farm programs affect the Nation's production response for the specific program crops? Because major grains are program crops, yield and production response for U.S. grains could be estimated by employing the changing ratio between fertilizer cost and commodity price, and the provisions of the ARP. Planting dates, crop rotation, tillage practices, and actual seeding rates each affect yield; however, this study does not attempt to specifically quantify their effects.

*The authors are agricultural economists with the Crops Branch, Economic Research Service, U.S. Department of Agriculture.

[1]Italicized numbers in parentheses cite sources listed in the References section at end of this report.

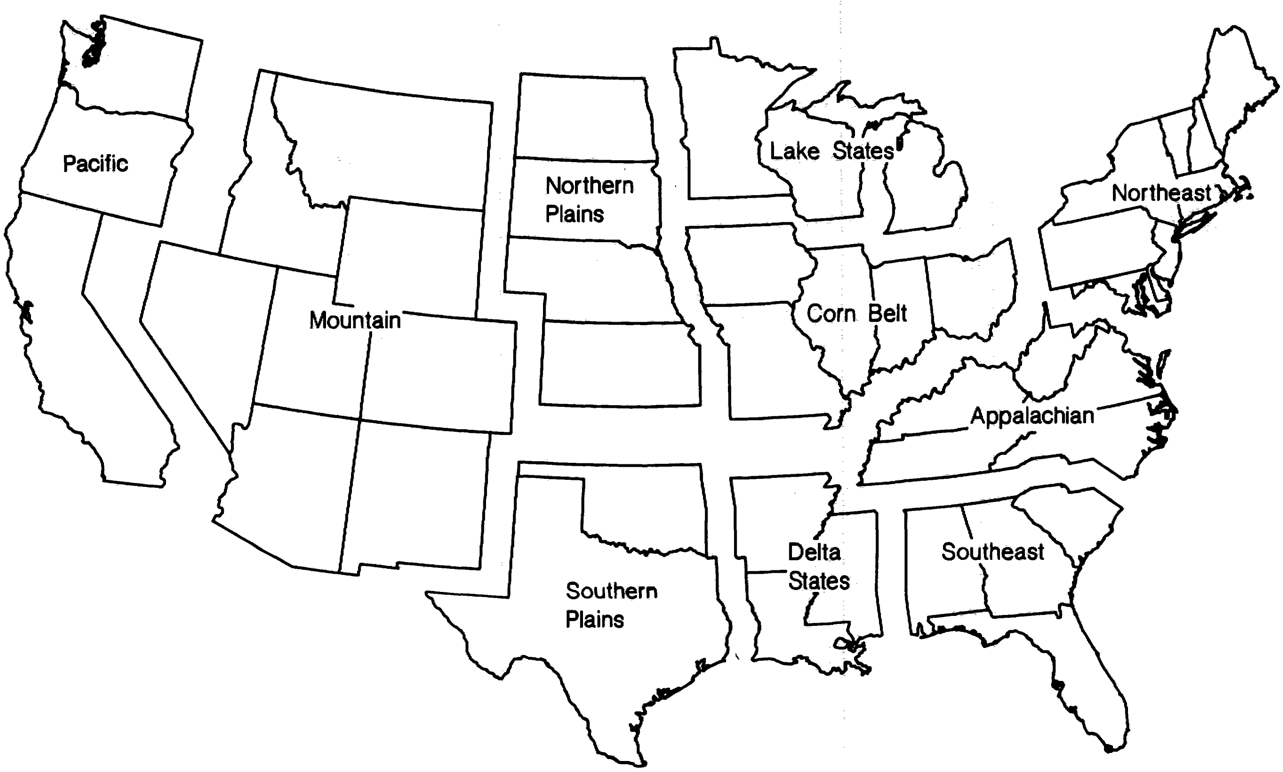
[2]Normal weather is seldom experienced but is frequently assumed for lack of better data about weather patterns.

We used ordinary least squares to develop yield equation estimates. This procedure was selected because it was the simplest and most convenient method of estimating parameters and was easiest to forecast with. By using deviations from the historical means for the weather data, we could mitigate statistical problems such as multicollinearity, an important adjustment to get reliable coefficients for interregional comparisons of yield impacts.

The weather data are regional aggregations, based on data collected by the National Climatic Data Center which reports daily precipitation values from various stations. The monthly figure is the average rainfall over all stations in a State. Daily average temperatures are the means of the highest and lowest temperature for the day, averaged over all stations. The sum of daily temperatures is divided by the number of days in the month to derive the monthly average. These monthly averages for precipitation and temperature are weighted by the State's harvested cropland, and the total over all States in that region equals the monthly regional average (*42*). These weather variables are expressed as deviations from longrun (1956-84) means. This method centers the data and gives it a mean of zero, making it convenient to project under assumptions of normal weather conditions. Therefore, crop-yield projections under normal weather can be made simply by using the technological trend, relative expected price ratio of fertilizer to commodity, and expected acreage in each equation. This transformation also helps alleviate some of the collinearity in the equation between the linear and curvilinear terms and improves the likelihood of good parameter estimates.

The validity of these models depends on the constant values of the parameters over time and the assumption that no drastic deviation from normal weather occurs. If the models are well-specified, the weather coefficients should be measurable and their impact on yields predictable. Any extreme deviations from normal weather in terms of not only monthly average but also intramonthly distribution patterns would cast doubts about the estimated yield relations. Technological advances may make these equations obsolete if the biological production functions for these crops are dramatically altered. Earlier studies do not support assumptions of nonrandomness or cyclical weather behavior (*20*). Analysis of the data also suggests that the variabil-

Figure 1
Farm Production Regions



ity from the mean temperature and precipitation does not differ across regions but is more volatile in the winter months compared with the summer for all regions. In most regions there is a high correlation between relative yield changes of the different grain crops.

Factors Affecting Crop Yields

This section discusses factors that affect crop yields of U.S. grains. Soil moisture, measured in terms of cumulative rainfall prior to the growing season, and temperature and precipitation in critical months are identified and discussed for both food grains and feed grains.

Wheat

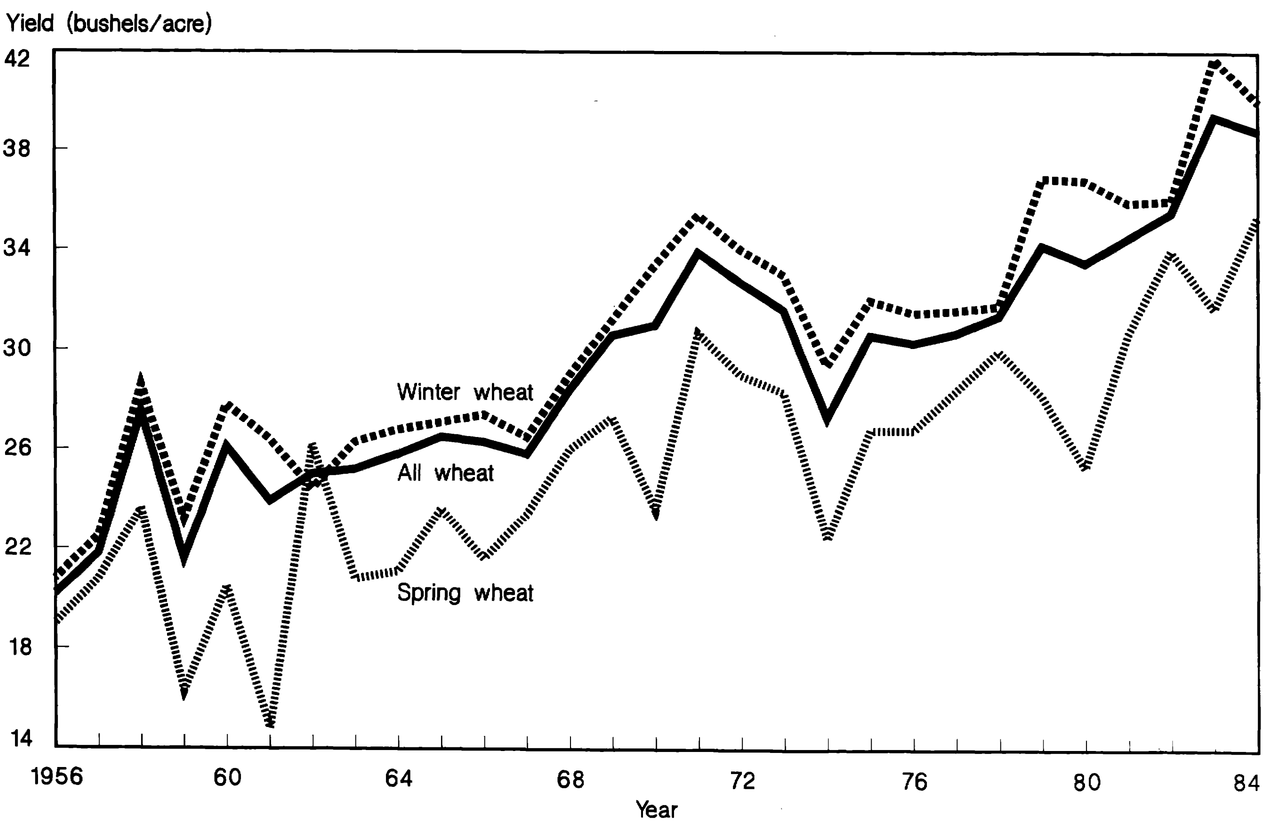
Wheat, the third most important crop in the United States, ranks behind corn and soybeans in terms of acreage and value of production. In 1984, farmers planted 79.2 million acres to wheat, which is comparable to the acreage in the early 1950's. The major trend in wheat production has been the steady increase in average yields, rising from about 20 bushels per acre in 1956 to almost 40 bushels (fig. 2). Yields have ranged from 60 to 80 bushels in States where irrigation is common. Yields have risen above 100 bushels per acre in some European countries, such as Great Britain and France, where inputs like fertilizer are used more intensively than in the United States.

Farmers grow five major classes of wheat in the United States: hard red winter (HRW), soft red winter (SRW), hard red spring (HRS), white, and durum. The differences show up in the protein content of the wheats and in milling and baking properties of flour produced from each. These classes of wheat differ in their adaptability to various environmental factors and span different geographic areas. Winter wheat is grown where the winter is relatively mild, and planting is done in the fall. Farmers plant spring wheat and durum after the spring thaw in areas where extremely low surface temperatures would kill seedlings.

The first semidwarf wheat varieties appeared in 1961. By the late 1970's, semidwarfs had been widely adopted and yields began to rise. These varieties were developed by crossing different existing vari-

Figure 2

Yield trends for the United States, all, winter, and spring wheat



eties with desired genes to produce wheat with large heads and short, stiff straw, which makes the plant resistant to lodging damage caused by high winds and heavy rains. Semidwarfs are highly responsive to soil fertility. The first semidwarf wheats were spring varieties. Acreage planted to semidwarf varieties increased from 2.9 percent of all wheat area in 1964 to 58.7 percent by 1984. Of the States with wheat yields above the national average, most have a high percentage of acres planted to modern semidwarf varieties (4).

The leading wheat variety over the past several years has been Newton, an HRW wheat which occupied 4.8 million acres in 1984, making up 11.2 percent of the acreage planted to that class. Marshall has recently been the most successful HRS variety, seeded to over 2.6 million acres, 19.6 percent of all acreage in spring wheat (*24*).

Hybrid wheats, released by private firms only a few years ago, have yielded about 10 percent more than conventional varieties. Due to the high cost of hybrid seeds, about 3-4 times the cost of conventional varieties, and low wheat prices, hybrid wheat acreage in 1984 amounted to less than 0.1 percent of total wheat acreage. Experts now predict hybrids will account for less than 10 percent of all wheat acreage by 1990, unless the yield differential and wheat price rise and/or seed costs decline.

Increases in fertilizer use have resulted in progressively higher grain yields. Growers applied fertilizer to 77 percent of wheat acreage in 1985, mostly before or at the time of planting (*30*). Some farmers have begun to apply a top dressing of nitrogen several times during the spring to minimize runoff, and consequently, improve yields. This is a much more common practice in Europe where some of the world's highest wheat yields are achieved. The average U.S. nitrogen level was 60 pounds per acre in 1985, up from 29 pounds in 1964. Use of phosphate and potash, important nutrients for early root and leaf development and building of strong, stiff stalks, has also increased sharply. The Corn Belt has the highest application rate, followed by the Pacific Northwest, Lake States, Southern Plains, Northern Plains, and Mountain States. The availability of adequate soil moisture may be a far more critical factor when fertilizer application rates rise in the major production States.

Irrigated land made up 6.6 percent of all wheat acreage, according to the 1982 Census of Agriculture (*40*). The average yield for irrigated land was 64.3 bushels per acre compared with 31.8 bushels on dry land. Most of this acreage is in the Southern Plains where 896,900 acres were irrigated in 1982, or 17.6 percent of all irrigated acres. Almost all of the wheat in Arizona and 75 percent in California is irrigated. Wheat requires about 24 inches of water during the growing season for maximum yields.

With the adoption of shorter strawed, semidwarf varieties, herbicide use has become more important to prevent weeds from crowding out the wheat and depleting soil moisture and nutrients. Control of broadleaf weeds, mustards, and thistles and grasses like wild oats and quackgrass necessitated the application of 16 million pounds of herbicide in 1986 (*30*). Hessian flies, grasshoppers, and chinch bugs are among the most damaging insect pests. Powdery mildew and leaf and stem rust attack plant tissue, obstruct photosynthesis, and inhibit grain development (*22*). The Newton variety has a fairly good resistance to rust and outperforms other varieties when epidemics become serious. Chemical fungicide treatment of the seed sometimes reduces the virulence of certain diseases. An effective chemical application is phenyl mercury acetate (*8*).

Dalrymple has reported that 45-51 percent of the yield increases in Minnesota between 1940 and 1975 were due to breeding, 19-26 percent to fertilizer and herbicides, and 26-32 percent to mechanization (4).

Other factors that also may affect wheat yields are planting date, fallow, crop rotation, tillage practices, and seed size. Early seeding of spring wheat, usually in late April, allows the seedlings to get a good start against weeds and potential diseases. Planting between the last 2 weeks of September and mid-October generally is best for winter wheat, as winter wheat planted prior to these dates is subject to infestation by the hessian fly. Wheat planted after those dates does not allow for adequate root development and is subject to winterkill, which may occur when there is an inadequate amount of protective snowcover. In studies of the Newton variety, large seeds outyielded smaller seeds by nearly 10 bushels per acre (6). Large seeds are more vigorous and germinate faster so that tolerance to disease and cold is superior to smaller seed samples. However, planting smaller seeds at higher rates, about 75-90 pounds per acre versus an average 60, may compensate in part for smaller seed and later planting dates. Seeds should germinate at rates of at least 85 percent for a good stand. Corn or sunflowers preceding spring wheat in the rotation has become a less prevalent practice than in the past because of modern, highly effective herbicides.

Timely tillage helps reduce weed and insect populations but must be used sparingly to conserve soil moisture, prevent erosion, and minimize production costs.

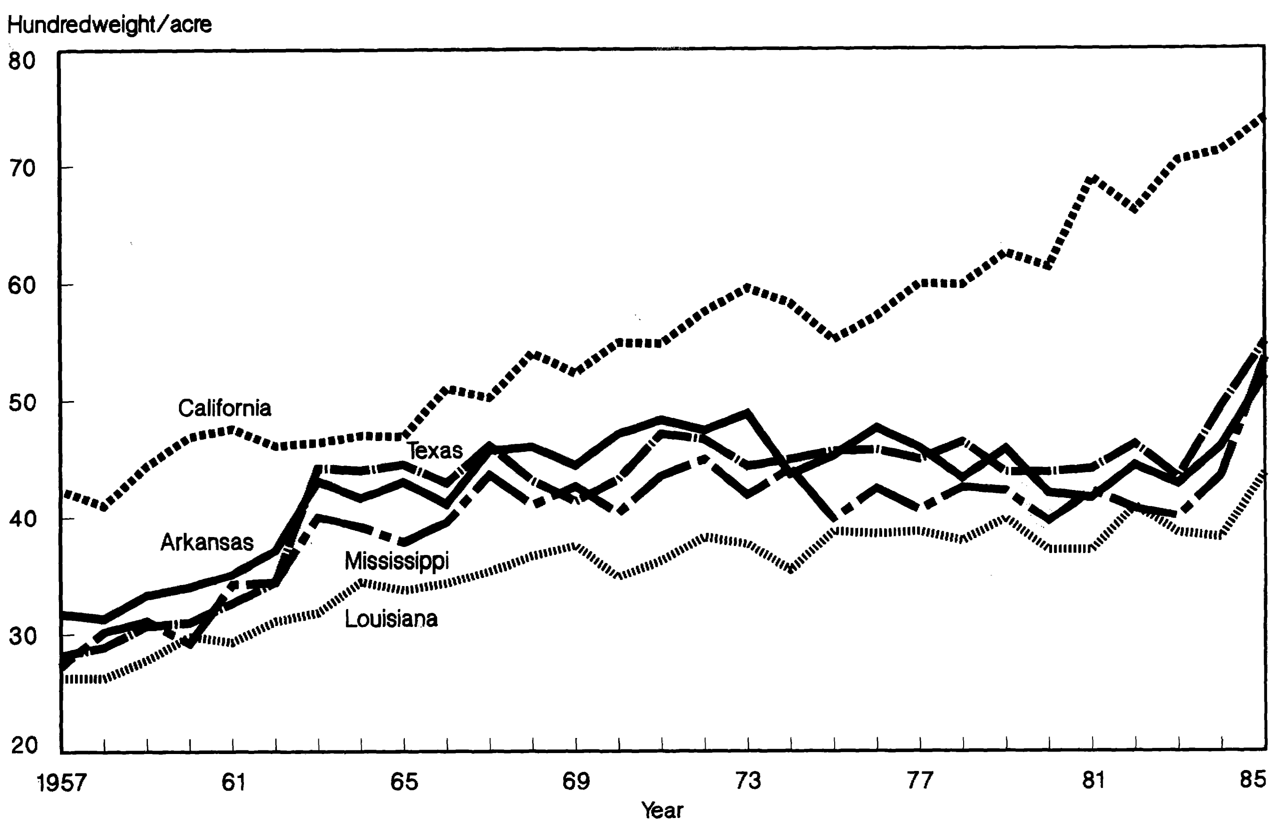
Wheat does not require as much precipitation as corn or soybeans, so the areas in which it can be grown profitably are much larger. A minimum of 4 inches of available soil moisture is necessary to grow winter wheat to the kernel-setting stage. Excessive rainfall during April and May can delay spring planting to the point where yields may be more vulnerable to adverse summer conditions. Fieldwork during the wet spring may compact soil, producing a poor seedbed and uneven stands. Temperature also affects yields. When heat stresses young plants, they may wither or ripen prematurely with shrunken heads and shriveled kernels, which is more of a problem for spring wheat than winter wheat. Warmer springtime temperatures generally assist the development of fall-sown wheat. However, such conditions also may aggravate insect and disease problems later in the season.

Rice

U.S. rice production is limited primarily to six States. Rice grows most successfully under conditions similar to the semitropical environment of Southeast Asia where it first appeared. Growing rice mainly consists of: flooding level fields with fresh irrigation water; warm, sunny days with temperatures at 70-88 degrees during the growing season; and draining before harvest. Long-grain rice is the dominant class, with 75 percent of the acreage in 1984. Medium- and short-grain rice varieties accounted for 21 and 4 percent (35). Both medium- and short-grain varieties are concentrated in California's more temperate climate.

Over the past three decades, U.S. rice production more than tripled, and output increased from 48 million hundredweight (cwt) in 1952 to 136 million cwt in 1985. While part of the production expansion was due to increased acreage, especially beginning in 1974 when marketing quotas were suspended, it was also the result of an upward yield trend during 1952-72 (fig. 3). After a downturn in rice yields in

Figure 3
Rice yields, by State



1973, yields in California accelerated while yields in the South (Arkansas, Louisiana, Mississippi, and Texas) leveled off, then increased in 1984 and 1985. The most important factors contributing to the upward trend in yields were improvements in technology and production practices, herbicide and varietal breakthroughs in the early 1960's, and increased rates of fertilizer application.

Farmers plant rice seed about 1 inch deep with a grain drill on dry land, or water- or dry-seed from an airplane. Seeding rates on average vary from 104-135 pounds per acre using a grain drill, and 121-172 pounds per acre with the broadcast (water-seed) and aerial methods (*21*). The best time for seeding depends on the varieties used, geographic areas, and prevailing conditions. Most rice is planted between March and June, when the optimal soil temperatures for good germination are 86-90 degrees.

In the South, rice requires 2.8–3.8 acre-feet of water to produce a crop, compared with California where the average is 8.2 acre-feet because of higher evaporation and lower humidity. Timely flooding and drainage is essential for weed control, temperature regulation, conditioning the seedbed for planting and harvest, and maximizing yield. The fields on which rice is grown are generally level to facilitate irrigation, because the land is submerged by 4-6 inches of water for part or all of the growing season. The best soil is nonalkaline, heavy clay and silt which prevents the loss of water through seepage (*28*).

Various methods counteract the detrimental yield effects of rice pests, the most serious of which are tall weeds like barnyardgrass, the rice stink bug, and the rice water weevil which attacks the plant's root system. Diseases such as blast fungus and sheath blight are common under conditions of frequent rains, heavy dew, and high humidity. Varieties are being bred to resist these diseases while chemicals like propanil, carbofuran, and methyl parathion are widely used to control pests.

A split application of fertilizer may be drilled or broadcast again prior to planting and broadcast again onto the water by airplane during panicle formation. The method and timing of fertilization are important to minimize plant nutrient stress and nitrogen contact with oxygen, which leads to denitrification and the plant's inability to use nitrogen during the growing period.

Modern short-strawed rice varieties, like wheat, respond well to fertilizer for high yields and also resist lodging (which leads to difficulties in harvesting and poor milling quality). During the 1960's, some of the more notable varietal introductions included Bluebelle (released from Beaumont, Tex., in 1965) and Starbonnet (released from Stuttgart, Ark., in 1967). Both varieties are short-strawed and resistant to lodging. Since 1970, some of the better short-strawed rice varieties that were introduced in the southern rice areas include: Nortai (Arkansas, 1972), Brazos (Texas, 1974), and Mars (Arkansas, 1977). During the late 1970's, the introductions of the long-grain varieties, LaBelle and Lebonnet, were significant advancements (*4*).

Recently, semidwarf long-grain varieties including Bellemont, Lemont, Newbonnet, Gulfmont, and Rexmont were released for commercial use in the South. In 1984, the acreage was estimated at 176,000 acres. Texas growers alone planted 155,000 acres of semidwarf, long-grain rice, or 38 percent of the State's rice acreage. Some analysts have projected that by 1987 there will be 300,000 acres in Texas and over 1 million acres of semidwarfs in other Southern States. The most popular short- and medium-grain semidwarf rice in California are S-201 and M-201, which made up 20.5 and 46.4 percent of the State's acreage, respectively, in 1984. Semidwarfs accounted for an estimated 86 percent of all California rice area. Average yields for M-201 in experimental plots have been as high as 8,310 pounds an acre. Over 616,000 acres were planted to S-201 and M-201 in 1984, which was 21.9 percent of the total U.S. acreage, up from 8.9 percent in 1979 (*5*). These varieties have the potential to increase yields 25 percent and reduce the cost of good-quality rice $1.05 per cwt (*11*).

Unstable weather conditions and variations in area harvested have caused wide variations in U.S. rice yields. For example, U.S. average rice yield dropped from 47 cwt in 1972 to 42.7 cwt in 1973. In Texas, the yield dropped from 47.4 cwt to 37.4 cwt, a decrease of 20 percent in 1 year. Two important factors caused the decreases: late planting due to a wet spring in Mississippi, Arkansas, Louisiana, and Texas and a hurricane just prior to harvest in Texas. The suspension of marketing quotas in 1974 and subsequent years allowed rice farmers to expand acreage planted to rice in all rice-producing States. The acreage expansion was especially significant in Arkansas where harvested rice acreage jumped from 533,000 acres in 1973 to 725,000 in 1974. This increase complicated farm management and may have caused delays in rice planting because management practices and resources tended to be fixed in the short run. Partly because of the expansion, rice yields in Arkansas fell from 47.7 cwt to 45.4 cwt.

Corn

Of all the technological developments of the past century, one of the most revolutionary has been the advance in corn yields (fig. 4). Average U.S. corn yields rose from 25 bushels in the 1930's when hybrids were first introduced to nearly 50 bushels per acre in the mid-1950's and 119 bushels in 1986. Production in 1985 reached 8.9 billion bushels, making it the largest corn crop ever.

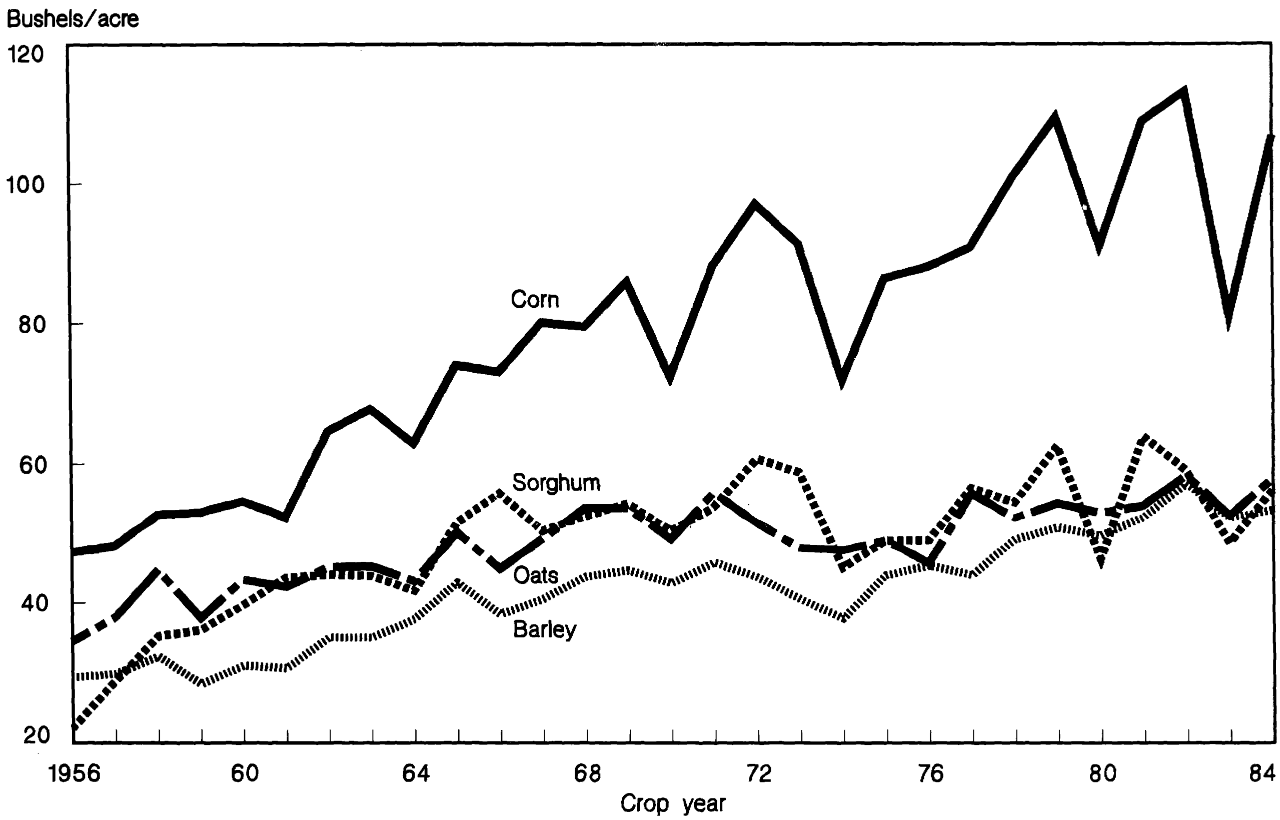
These gains grew from the development of high-yielding hybrids, many of which have been introduced by private companies along with publicly supported research. Plant breeders have selected varieties that flourish in the presence of high levels of nitrogen. Higher plant populations per acre, increased irrigation, and widespread adoption of a corn/soybean rotation have also elevated yields. However, there may be a cost to an ever-increasing monoculture. If widespread use of very closely related varieties becomes common, the total crop may be more susceptible to catastrophic diseases or extreme drought, as in the corn blight in 1970 and droughts in 1980 and 1983.

Longrun prospects for productivity gains appear to be bright for corn and other grains. Technological breakthroughs in the areas of regulation of plant growth with hormones, photosynthetic enhancement, cell and tissue culture technology, recombinant DNA and gene transfers, and biological nitrogen fixation all could accelerate corn production in the next decade and enhance the potential of end uses of the crop.[3]

Improved corn hybrids have generated noticeable and persistent increases in planting rates. New varieties are superior in root and stalk strength and the ability to withstand stress. These characteristics have enabled new hybrids to improve yields under high plant population conditions.

[3]If a new corn plant were developed so it could mature in a much shorter growing season, or could fix its own nitrogen requirements as do soybeans, or had a much higher protein content, food costs would likely plummet in the future (28).

Figure 4
U.S. feed grain yield



Shorter growing season varieties are being developed which produce high yields, and mature earlier (as quickly as 80–90 days) than other varieties. Short-season hybrids are necessary to achieve good yields in areas where the number of growing-degree days (days when mean temperature exceeds 50 degrees) is limited. These hybrids helped nearly double the Lake States' share of U.S. corn acreage from 9 percent in 1950 to the current 17 percent.

Not only is normal moisture and temperature required for high corn yields but timing of maturation is crucial. Corn requires soil temperatures above 50 degrees for germination to occur. About 60 days after planting, when the corn enters the tasseling and silking stages, rainfall or adequate soil moisture is crucial for normal ear development. This occurs in the Corn Belt from July 10 to August 10, depending on planting dates. Over half of the corn crop is normally planted by May 15, and 80 percent of the crop is mature by the last week in September. Different hybrids have varying rates of maturity, which can reduce yield variability, since a farmer can change varieties according to the time of planting. One-and-a-half inches of rain per week during July, which is slightly above normal for this region and 2 degrees below normal temperature are the best conditions for good corn yields. Corn grows best at 75–86 degrees. Temperatures above that require that the plant take in more water to sustain the stalk, which inhibits the development of viable pollen and normal ears.

There is a strong interaction between moisture levels and the amount of available nitrogen in the soil. Fertilizer use increased 35 percent during the 1970's, a time of great expansion in corn production. Nitrogen application on corn averaged 140 pounds per acre in 1985, and 97 percent of the corn acres received some nitrogen, 74 percent at or before the time of planting (*30*). Growers in the Plains States may irrigate up to 70 percent of their corn, raising yields by 45 percent over nonirrigated land. In 1982, 8.5 million acres of corn were irrigated in the United States, or about 10 percent of total corn area (*40*).

Pesticide use increased by 80 percent in the 1970's. U.S. corn farmers reportedly treated their acreage with 248 million pounds of herbicides and 30.6 million pounds of insecticides (both in terms of active ingredients). The major targets were foxtails and cockleburs, and rootworms, cutworms, and corn borers (*26*). Smaller amounts of fungicides combat seed rot, smut, or blight. Use of these chemicals has picked up in the past few years as more farmers adopt reduced tillage techniques for soil conservation. Perhaps upwards of half of the corn farmers now practice reduced tillage, but no evidence exists of appreciably different yields from other cropping systems.

Almost half of the corn acreage is rotated with soybeans. Studies show that a corn-soybean rotation can result in a 15-percent increase in corn yield and a smaller increase in soybean yield because of better control of plant insects and diseases (*27*).

Unstable weather conditions, corn diseases, and variations in area planted caused wide yield variability. For instance, the late spring in 1974 caused late planting and, combined with an early frost, sizably reduced yields in the Lake States that year. Southern corn leaf blight in the eastern Corn Belt and Southern States lowered yields drastically in 1970. Drought in 1980 and 1983 reduced yields substantially.

Recent research has revealed that agricultural supply control programs may also affect yields. As more corn acreage is taken out of production, farmers plant their crop on their most productive land. These acres also receive more intensive management and increased use of inputs, like fertilizer and pesticides. So, actual production falls by less than the proportion of acreage set aside because average yields have gone up (*3*, *19*).

Sorghum

Sorghum, or milo as it is sometimes called, ranks second only to corn as a feed grain when measured in terms of quantity produced. Acreage and production have fluctuated since 1950, with yields having risen significantly before 1972. Over 16.6 million acres were harvested in 1985, resulting in an output of 1.1 billion bushels, a record high (app. table 13). Most of this acreage was in the Southern Plains and Kansas. In the past 4 years, growers have increased acreage substantially in the South. Arkansas, Louisiana, Tennessee, and Mississippi have all expanded their sorghum acreages, harvesting 2.4 million acres in 1985, an increase of 195 percent from 1983 (*34*). However, 1987 plantings will be down considerably from this level. The willingness of farmers to invest in grain-drying facilities and wheat-sorghum double cropping in these States shows how sorghum has gained acceptance by the industry and that it may become a profitable crop.

Sorghum is more resistant to extremes in precipitation and temperatures than most other crops. It also can grow well on sandier, hilly soil. Although dryland sorghum does well, irrigated acreage produces higher yields. During the 1970's, more irrigated land was shifted into corn and out of sorghum production. However, as water tables drop and the costs of pumping from wells climb, a return to the more water-efficient crop may result.

Gated pipes and sprinkler systems have been the most prevalent irrigation methods and have replaced the less efficient open ditches in most areas (*10*). In 1982, 2.2 million acres were irrigated, accounting for 15 percent of total sorghum area.

Planting generally begins in May, and half of the crop is planted by the first week in June. Sorghum requires higher soil temperatures (at least 65 degrees) to germinate, with the optimal range at 89-95 degrees. Sufficiently warm temperatures early in the season will enhance yields by fostering germination and rapid growth. Seeding rates are highest on irrigated land, 12-18 pounds per acre, but lower seeding rates of 3-6 pounds on dryland are often more economical and yield just as well (*7*). Harvest normally takes place between July and October (*17*).

With the introduction of new sorghum hybrids in 1956, yields have about quadrupled in many areas (app. tables 14-16). Hybrids, used almost completely now in the United States, can achieve high, stable yields at southern latitudes, even under conditions of short days, high night temperatures and humidity, and high disease incidence. In Texas, for example, these new hybrids offer a 20-percent increase in yield potential. Plant breeding breakthroughs in identifying and selecting drought-resistant characteristics and improvements in feeding value would accelerate the production of sorghum in the mid-South and Southeast.

Sorghum has high nitrogen requirements, and optimum levels are about 80 percent of the amount needed by corn. While nitrogen use varies geographically, irrigated sorghum usually receives more nitrogen (53-133 pounds per acre) than dryland sorghum (9-102 pounds per acre). Such plant nutrients as phosphorus, potash, and lime also are added to the soil in large quantities because of their importance in the early growth of leaf area, which can determine potential grain yield later in the season.

Insects and weeds are chronic barriers to high yields. The major insect pests are greenbug and sorghum midge in the South and chinch bugs in the Plains. Common weed pests are pigweeds, johnsongrass, cockleburs, and foxtails. In 1976, a sample indicated that farmers treated 42 percent of sorghum acreage for weeds and 28 percent for insects. Only a few acres were treated for diseases (*8*). An integrated crop management system has become common, involving resistant varieties, timely planting dates, crop rotation and intercropping, and extensive use of pesticides, herbicides, and other chemicals.

The critical months for temperature in the Southern Plains begins in April, when warm weather favors sorghum. Extremely hot days, however, will hurt crop development prior to harvest. Soil moisture before planting and precipitation during June and July are important in the Southern Plains. To the north, precipitation in later months is more critical.

Barley

Production of barley in the United States centers chiefly in the northern tier and West Coast States. Total output has gradually increased, having reached a record 610.5 million bushels in 1986. The four primary regions (Pacific, Lake States, Northern Plains, and Mountain States) accounted for 97 percent of U.S. barley production. Appendix tables 17-21 show the historical data of U.S. barley acreage, yield, and production, and similar data for the primary regions.

Ideal growing conditions for barley vary depending on the crop's final use. Barley is grown primarily for its feed value and secondarily for malt as the primary ingredient in the brewing industry. A 13.5-percent protein content is the criterion in the selection of barley for malting, and different farming practices are required to supply this market. Malting barley grows mostly in Montana, the Dakotas, and Minnesota, while feed barley is grown in California and the Pacific Northwest. To improve yields and protein content of feed barley, farmers increase fertilization and irrigation, which explains in part why yields are higher on average in feed barley regions than malting barley areas.

U.S. barley acreage has been declining since the 1950's. However, in some States, notably Idaho and Montana, acreage has gradually risen since 1965, with much of it as feed barley. California has reduced its barley acreage in recent years. At the same time, Washington has increased its barley production, with an increasing proportion of its barley production destined for malting. Minnesota has the greatest proportion (usually over 90 percent) of acreage devoted to malting barley production. Acreage reduction programs on competing crops significantly affect barley planting. For instance, during the 1983 payment-in-kind (PIK) program (under which barley was not included), barley acreage soared, especially in the Northern Plains.

Yields have almost doubled in all regions during 1954-85, hitting a U.S. average of 51 bushels per acre in 1985 (*31*). Serious summer droughts during 1974, 1980, and 1983 substantially reduced yields in the Great Plains.

Spring-sown barley is best suited to cool, dry climates. Excessively warm temperatures will reduce yields and raise protein content above the 13.5-percent level considered desirable for malting purposes. Although adequate moisture is a necessary condition for good growth, too much rainfall can diminish output if there is a delay in planting. Excessive rainfall may bring hail or lodging, susceptibility to diseases, and bleaching and sprouting in the swaths of cut, but unharvested, grain.

Barley varieties for malting fall into two classes: six-rowed and two-rowed. This refers to the number of kernels on a node of a barley head. Varieties are selected for maximum malt yield, chemical composition, and plump kernels with at least 96-percent germination. Steptoe and Klages are popular two-rowed varieties in the Mountain States. In the Northern Plains, the six-rowed varieties Robust, Morex, and Azure are the most prevalent. These mature fairly early (heading within 28 days), are resistant to stem rust, and yield up to 70-80 bushels per acre. Some varieties have been bred to grow in soils with higher than normal levels of salinity.

Feed barley can achieve yields of 80 bushels per acre when total available soil nitrogen is at 200 pounds per acre. Malting barley responds well to levels of 100-120 pounds of nitrogen if planted by early May, but higher levels of nitrogen may push protein content above 13.5 percent. If planting is delayed to early June, 85 pounds of nitrogen is the maximum recommended. Although recommended seeding rates vary (given available nitrogen and moisture), 72-96 pounds is the optimal range.

Disease is a major problem in barley production in some areas. Fungal parasites like scab, smut, rust, and the barley yellow dwarf virus can reduce yields in very humid conditions. In 1985, very dry conditions prevailed in the Mountain and Pacific States, and a serious infestation of grasshoppers doomed the harvests in Idaho and Montana. Only the mass spraying of pesticides prevented further yield losses. Other pests that plague barley includes armyworms, mustard, and assorted broadleaf weeds.

Oats

U.S. oats production has declined from 1.4 billion bushels in 1958 to about 384 million in 1986, the smallest crop in 100 years, and down more than 73 percent in 29 years. Oats has become less important as a feed grain compared with corn, sorghum, and barley over this period. However, oats is still important in feeding horses, dairy cattle, and young calves (*33*).

Although oats acreage has fallen, average U.S. yield has risen from 34.5 bushels an acre in 1956 to 63.6 bushels in 1985, offsetting part of the decline in area harvested. Figure 4 shows that the rise in oats yields has lagged other feed grains. The upward yield trend for oats has been at a 1.6-percent annual rate compared with 3.8 percent for corn. If the trend continues, U.S. oats yields may continue to increase by 0.7 bushel per acre per year versus 2 bushels for corn. If oats is to maintain its importance as a feed grain, it should at least match the productivity growth of other feed grains.

Oats yields grew at a faster rate in the 1950's and 1960's than in the 1970's when they did not substantially increase. In contrast to other major field crops in the 1970's, irrigation was not a common production practice. Less than 2 percent of the country's 300,000 oats producers irrigated even part of their crop. Farmers irrigated about 14 percent of corn acreage in 1980 (mainly in semiarid regions), producing yields 45 percent higher than on unirrigated land. Producers shifted oats from higher quality land to less productive soil because oats is one of the most adaptable crops to areas of low rainfall and marginal farmland. Corn Belt and upper Midwest oats is almost always on the grower's poorest land. Farmers applied commercial fertilizer on 35-40 percent of the oats acreage harvested for grain, low application rates compared with other crops. For example, 10-17 pounds of nitrogen per acre were applied to oats in 1978 in the Northern Plains, compared with 118-131 pounds of nitrogen applied to corn in the Corn Belt. The decline of oats as a major field crop has reduced the investment in oats breeding research and development of improved production practices that have contributed to higher yields in corn, barley, and wheat.

Genetic improvements over the past 35 years have focused on increasing yields and improving disease resistance. The barley yellow dwarf virus, and rust and smut which are fungal parasites, have been major problems for growers. Some disease-resistant varieties have shown promise but have failed after a period of 3-7 years when more virulent strains of fungi became dominant. Treating seeds with chemicals and planting fields with more than one variety can also inhibit the spread of disease. Another favorable genetic characteristic is resistance to lodging caused by high winds and heavy rain. Biotechnology may accelerate the genetic capabilities of all major feed grains including oats.

The ideal weather conditions for oats are cool temperatures and abundant moisture. Planting usually starts in the northern regions by early April, and harvest is completed by the end of August. Seeding rates can vary between 80-96 pounds per acre, and higher rates are common if the seed is broadcast. By early July, much of the crop will be in the kernel-filling stage. The weather conditions up to this point will have a critical impact on the yields as well as the feed quality which is reflected in test weight per bushel and protein content. Time of planting also affects oats yields. Sufficient, but not excessive, soil moisture permits early seeding and promotes maturation during the cooler spring months. The sooner spring oats reach the heading out phase the less susceptible the crop is to yield-reducing infestations of smut and rust.

Above-normal precipitation in the summer generally boosts oats yields since moisture is critical during the filling stage of the oats crop. Above-normal temperature in late spring through early summer tends to have an adverse effect on oats yields.

The presence of nitrogen in the soil can substantially elevate yields and protein content. However, the cost of fertilizer application often outweighs returns, making it unprofitable for farmers to fertilize. Residual amounts of nutrients left in the soil after the previous crop may also affect current yields of an oats crop. Very limited amounts of broadleaf herbicides such as MCPA may also be used in the three-to-four leaf stage, but most weed control comes from mechanical cultivation of the seedbed. For many growers, oats is simply used as a cover crop or a source of forage for their livestock, and grain yield is not the most important consideration. When other major crops are put into an APR, oats acreage typically climbs, becoming a soil-conserving alternative. In 1983, during the PIK program, acreage seeded to oats rose to 20 million acres. Only 45 percent of this crop, however, was actually harvested for grain. Yields may thus indirectly depend on the purpose for which the crop is planted.

Estimated Wheat Yield Equations

Equations 1-12 represent the yield response functions for all wheat, winter wheat, and spring wheat for the Northern Plains, Southern Plains, Mountain, Pacific, Corn Belt, and Lake States regions. Together these regions constitute over 90 percent of U.S. wheat acreage and production. The years 1956-84 were selected as the study period. This period is short enough for the assumption of linear yield trend to hold, and long enough to allow for sufficient degrees of freedom in estimating the equations.

Northern Plains

The specifications for the yield equations for all wheat, winter wheat, and spring wheat were similar. However, the critical months for precipitation and temperature come later for spring wheat than for winter wheat. This may account for differing signs of some rainfall variables, since winter wheat may be in the harvest stage and be adversely affected by rain. The opposite would be the case for spring wheat that is still in the vegetative or reproductive stage. Only the Northern Plains region grows substantial amounts of both winter and spring wheat, which may produce different parameters in the all-wheat equation rather than in the individual equations for both types.

The yield trend for all-wheat rose by 0.77 bushel per acre per year, about 2.9 percent on average. Since the Northern Plains region accounts for nearly 40 percent of the Nation's wheat, much of the growth in the national wheat yield has resulted from technological advances there. Figure 5 illustrates the close relationship between precipitation and yield, where all the data have been standardized to a normal distribution so that there is a common unit (z score) with a mean of zero and standard deviation of 1. This permits a comparison of how the respective relative changes in March and May precipitation are positively and negatively correlated to winter wheat yield, although other weather influences not depicted also may affect yield in certain years.

Within limits, above-normal soil moisture (measured as cumulative precipitation from July through March) tended to raise all-wheat and spring wheat yields in the Northern Plains. Above-normal precipitation in June and July were generally beneficial for spring wheat, while excessive July temperatures held yields down. Winter wheat yields responded favorably to March rains but declined because of excessive May and June precipitation.

Above-normal temperatures in June and July tended to reduce winter wheat yields by 0.8 and 0.9 bushel an acre, respectively.

Expected fertilizer prices relative to lagged wheat prices were significant in the all-wheat equation. Wheat yields tended to increase 0.04 percent as a result of a 1-percent increase in wheat price. Due to model specification, wheat yields responded to changes in fertilizer prices by the same proportion but have the opposite relationship.

All-wheat[4] (1)

$$
\begin{aligned}
WYLD = & -1{,}469 + 0.77^{*}YEAR - 0.72^{*}PMAY \\
& (-14.1) \quad (14.2) \quad (-2.86) \\
& -0.93^{*}PJU2 - 0.86^{*}PJL + 0.11^{*}SM2 \\
& (-3.95) \quad (-2.19) \quad (1.94) \\
& -0.05^{*}TMC - 0.50^{*}TJU - 1.17^{*}TJL \\
& (-0.74) \quad (-3.57) \quad (-7.18) \\
& -0.0008^{*}PACRE - 0.08^{*}FERTP \\
& (-7.09) \quad (-2.11)
\end{aligned}
$$

$R^2 = 0.95$ DW = 2.64

Winter wheat (2)

$$
\begin{aligned}
WWYLD = & -1298.9 + 0.68^{*}YEAR + 2.02^{*}PMC \\
& (-3.57) \quad (3.83) \quad (2.00) \\
& -1.20^{*}PMAY - 1.31^{*}PJU - 0.78^{*}TJU \\
& (-1.93) \quad (-1.80) \quad (-2.48) \\
& -0.89^{*}TJL - 0.0013^{*}HACRE - 0.07^{*}FERTP \\
& (-2.88) \quad (-2.73) \quad (-0.33)
\end{aligned}
$$

$R^2 = 0.80$ DW = 1.75

Spring wheat (3)

$$
\begin{aligned}
SWYLD = & -1067 + 0.56^{*}YEAR + 2.10^{*}PJU \\
& (-5.88) \quad (5.91) \quad (3.37) \\
& -0.80^{*}PJU2 + 1.11^{*}PJL + 0.22^{*}SM2 \\
& (-1.73) \quad (1.65) \quad (1.96) \\
& -0.78^{*}TJL - 0.0005^{*}PACRE - 0.07^{*}FERTP \\
& (-2.80) \quad (-1.52) \quad (-0.74)
\end{aligned}
$$

$R^2 = 0.81$ DW = 2.14,

where WYLD = All-wheat yield, bushels per acre
WWYLD = Winter wheat yield, bushels per acre
SWYLD = Spring wheat yield, bushels per acre
YEAR = Technological trend (1956 = 1956)

PMC = Deviation from average March precipitation, inches
PMAY = Deviation from average May precipitation, inches
PJU = Deviation from average June precipitation, inches
PJU2 = PJU squared, inches

PJL = Deviation from average July precipitation, inches
SM2 = Squared deviation of average soil moisture, Jul.-Mar., inches
TMC = Deviation from average March temperature, degrees F.
TMAY = Deviation from average May temperature, degrees F.

TJU = Deviation from average June temperature, degrees F.
TJL = Deviation from average July temperature, degrees F.
TJL2 = TJL squared, degrees F.
PACRE = Planted acres, thousands

HACRE = Harvested acres, thousands
FERTP = Ratio of expected fertilizer price index relative to wheat price (lagged price for all-wheat and winter wheat and current price for spring wheat).

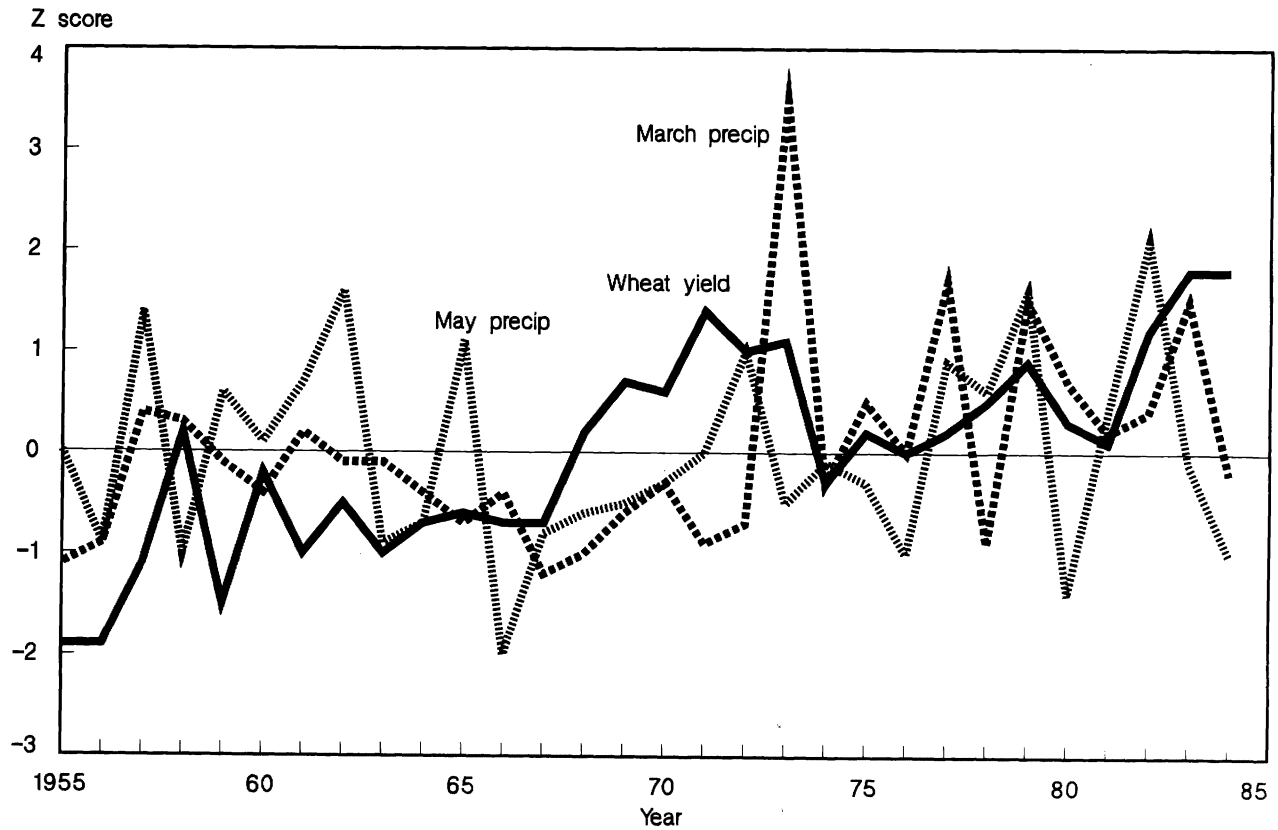
Southern Plains

The only class of wheat grown in the Southern Plains is winter wheat. This region accounts for about 20 percent of U.S. production. Yields grew at half the rate of the Northern Plains, 0.32 bushel per acre per year, and 1.3 percent of the current yield.

Above-normal soil moisture levels after planting and during the winter months are highly beneficial for wheat in this region. Wheat production areas in this region (especially the western portion) on average receive less rainfall than others but can achieve fair yields if the wheat gets an early start before the hot summer arrives. According to equation 4, a soil moisture level (measured as cumulative precipitation from the previous July through March) of 21 inches (or 1 inch above normal) is best.

[4]The figures shown in parentheses below the parameter estimates in all of the following equations are t-statistics. R^2 is the coefficient of determination, and DW is the Durbin-Watson statistic.

Figure 5
Northern Plains winter wheat yields and March and May precipitation



Hot weather during March, April, and May noticeably diminishes crop prospects. A degree above normal (71.9 degrees Fahrenheit) in May results in a decline in average yield of 0.8 bushel per acre, as shown by the following equation.

All-wheat (see footnote, p. 12) (4)

$$\begin{aligned} WYLD = & -600.9 + 0.32*YEAR - 1.22*PAP \\ & (-3.99)\quad (4.16) \quad (-2.62) \\ & + 0.19*SM - 0.09*SM2 - 0.27*TMC \\ & (1.47)\quad (-2.33)\quad (-1.73) \\ & - 0.41*TAP - 0.81*TMAY \\ & (-2.02)\quad (-2.51) \end{aligned}$$

$R^2 = 0.84$ DW = 2.04,

where SM = Deviation from average soil moisture, Jul.-Mar., inches
TMC = Deviation from average March temperature, degrees F.
TAP = Deviation from average April temperature, degrees F.,

with YEAR, SM2, and TMAY as defined earlier. Similarly, excessive precipitation in April leads to rust and disease problems and reduces yields. An inch of moisture above normal (2.5 inches) caused a 1.2 bushel-per-acre decline. Acreage and fertilizer price were not statistically significant for the Southern Plains.

Mountain Region

Much of the wheat in the southern sections of the semiarid Mountain region depends entirely on irrigation, but some spring wheat fields in Idaho and Montana rely completely on precipitation. All-wheat yields grew by an annual increment of about 0.5 bushel an acre, which is above that of the Southern Plains region.

Above-normal precipitation during the months of March and April for winter wheat and April and May for spring wheat are beneficial. A cooler than usual May and June are generally ideal conditions for winter wheat, whereas a warm April and cool June are best for spring wheat.

All-wheat (see footnote, p. 12) (5)

$$WYLD = \underset{(-6.84)}{-1001.9} + \underset{(6.94)}{0.53*YEAR} + \underset{(1.34)}{1.54*PAP}$$

$$+ \underset{(1.28)}{1.19*PMAY} + \underset{(1.17)}{1.90*PJL} + \underset{(1.84)}{0.16*TMAY2}$$

$$\underset{(-1.27)}{-0.14*TJU2} \underset{(-1.91)}{-0.0005*PACRE}$$

$R^2 = 0.88$ DW = 1.60

Winter wheat (6)

$$WWYLD = \underset{(-3.13)}{-619.9} + \underset{(3.20)}{0.33*YEAR} + \underset{(1.57)}{2.95*PAP}$$

$$\underset{(-1.47)}{-4.01*PAP2} \underset{(-1.57)}{-1.88*PMAY}$$

$$+ \underset{(0.55)}{0.95*PMC} + \underset{(1.06)}{2.02*PJL} \underset{(-1.98)}{-0.61*TMAY}$$

$$\underset{(-1.26)}{-0.28*TJU2} \underset{(-0.60)}{-0.0006*HACRE}$$

$R^2 = 0.83$ DW = 1.32

Spring wheat (7)

$$SWYLD = \underset{(-6.05)}{-883.6} + \underset{(6.22)}{0.46*YEAR} + \underset{(2.70)}{6.02*PAP2}$$

$$+ \underset{(1.39)}{2.54*PMAY2} + \underset{(1.57)}{0.78*SM} + \underset{(1.38)}{0.35*TAP}$$

$$\underset{(-1.82)}{-0.59*TJU}$$

$R^2 = 0.81$ DW = 1.64,

where YEAR = Technological trend (1956 = 1956)
PAP = Deviation from average April precipitation, inches
PAP2 = PAP squared, inches
PMAY = Deviation from average May precipitation, inches

PMAY2 = PMAY squared, inches
PJU = Deviation from average June precipitation, inches
PJL = Deviation from average July precipitation, inches
SM = Deviation from average soil moisture, Jul.-Mar., inches
TAP = Deviation from average April temperature, degrees F.
TMAY = Deviation from average May temperature, degrees F.
TMAY2 = TMAY squared, degrees F.
TJU = Deviation from average June temperature, degrees F.

TJU2 = TJU squared, degrees F.
PACRE = Planted acres, thousands
HACRE = Harvested acres, thousands

Pacific Region

The generally higher average yields in this region reflect extensive use of irrigation and high rates of fertilization. Yield has increased 2.9 percent annually, reflecting the adoption of these practices.

March, April, and May precipitation aid both winter and spring wheat yields (which also includes durum). However, 2.5 inches in April is the maximum amount that is necessary. A warmer temperature for the early growing season in April (above 50 degrees F.) and cooler than usual days in May and June (not to exceed 70 degrees F.) permit the maximum growth potential.

All-wheat (see footnote, p. 12) (8)

$$WYLD = \underset{(-6.57)}{-2407} + \underset{(6.59)}{1.25*YEAR} + \underset{(2.28)}{2.25*PAP}$$

$$\underset{(-3.20)}{-2.70*PAP2} + \underset{(1.81)}{2.83*PMAY} + \underset{(0.97)}{0.34*TAP}$$

$$\underset{(-2.79)}{-1.12*TJU} \underset{(-1.97)}{-0.42*TJU2} \underset{(-1.71)}{-0.003*PACRE}$$

$$\underset{(-0.76)}{-0.08*FERTP}$$

$R^2 = 0.92$ DW = 1.88

Winter wheat (9)

$$WWYLD = \underset{(-10.2)}{-1811} + \underset{(10.49)}{0.94*YEAR} + \underset{(2.01)}{2.08*PAP}$$

$$\underset{(-3.44)}{-2.84*PAP2} + \underset{(1.28)}{0.76*PMC} + \underset{(1.04)}{1.55*PMAY}$$

$$+ \underset{(1.13)}{0.40*TAP} \underset{(-3.39)}{-1.38*TJU}$$

$R^2 = 0.90$ DW = 1.86

Spring wheat (10)

$$
\begin{array}{llll}
SWYLD = & -1673 & +0.87*YEAR & +2.04*PMC \\
 & (-5.85) & (5.98) & (2.17) \\
 & +1.49*PAP & +3.48*PMAY & +7.89*PJU \\
 & (0.98) & (1.46) & (2.33) \\
 & +1.54*TAP & -0.45*TMAY2 & \\
 & (2.54) & (-1.97) &
\end{array}
$$

$R^2 = 0.78$ $DW = 1.24$,

where
YEAR = Technological trend (1956 = 1956)
PAP = Deviation from average April precipitation, inches
PAP2 = PAP squared, inches
PMAY = Deviation from average May precipitation, inches

PJU = Deviation from average June precipitation, inches
PJL = Deviation from average July precipitation, inches
TAP = Deviation from average April temperature, degrees
TMAY2 = Squared May temperature deviation, degrees F.

TJU = Deviation from average June temperature, degrees F.
TJU2 = TJU squared, degrees F.
PACRE = Planted acres, thousands
FERTP = Fertilizer price index-wheat price ratio, as defined earlier.

As fertilizer prices rise by 1 percent compared with the wheat price, yield tended to decline by 0.08 percent. However, it should be noted that this variable is not statistically significant in equation 8.

Corn Belt

The Corn Belt has been one of fastest growing corn production regions. Wheat remains a minor crop in the Corn Belt where yields have risen at a relatively slow 1.5-percent annual rate since 1956. Wheat fields in this region receive abundant moisture and fertilizer, however, which produce yields well above the U.S. average.

Normal amounts of rainfall for the Corn Belt may be too high to get the optimal yield potential for wheat. Maximum yields usually have occurred at less than average monthly precipitation levels for March and May, and with below-normal soil moisture between July and March. Winter wheat in the Corn Belt prefers warm temperatures in March and April, spurring rapid early growth. A 1-percent increase in fertilizer price (relative to the wheat price) led to reduced applications which curbed yields by 0.2 percent.

Winter wheat (11)

$$
\begin{array}{llll}
WWYLD = & -1012 & +0.54*YEAR & -1.59*PMC \\
 & (-10.5) & (11.1) & (-3.45) \\
 & -2.92*PMAY & -0.08*SM2 & +0.22*TMC \\
 & (-6.34) & (-2.38) & (2.22) \\
 & +0.26*TAP2 & 0.002*HACRE & -0.21*FERTP \\
 & (5.03) & (-3.79) & (-3.51)
\end{array}
$$

$R^2 = 0.93$ $DW = 1.68$,

where
YEAR = Technological trend (1956 = 1956)
PMC = Deviation from average March precipitation, inches
PMAY = Deviation from average May precipitation, inches
SM2 = Squared deviation soil moisture, Jul.-Mar., inches
TMC = Deviation from average March temperature, degrees F.
TAP2 = Squared April temperature, degrees F.
HACRE = Harvested acres, thousands
FERTP = Fertilizer price index-wheat price ratio, as defined earlier.

Lake States

The severe winters and short growing season of the Lake States limits this region to mostly spring wheat. New production techniques and spring wheat varieties have boosted yields 2.3 percent, or by two-thirds bushel, per year. This is comparable to the Northern Plains trend.

Spring wheat (12)

$$
\begin{array}{llll}
SWYLD = & -1298.0 & +0.67*YEAR & +0.57*PJU \\
 & (-10.4) & (10.6) & (1.10) \\
 & +0.15*SM2 & -0.05*TMAY2 & -1.23*TJL \\
 & (2.80) & (-1.14) & (-4.44) \\
 & +0.25*TAU2 & -0.18*TSP2 & \\
 & (2.11) & (-1.68) &
\end{array}
$$

$R^2 = 0.87$ $DW = 1.65$,

where YEAR = Technological trend (1956 = 1956)
PJU = Deviation from average June precipitation, inches
SM2 = Squared soil moisture deviation, Jul.-Mar., inches
TMAY2 = Squared May temperature deviation, degrees F.

TJL = Deviation from average July temperature, degrees F.
TAU2 = Squared August temperature deviation, degrees F.
TSP2 = Squared September temperature deviation, degrees F.

Abundant soil moisture and June precipitation are the most important factors affecting spring wheat yields in the Lake States. Equation 12 shows that each additional inch during June will raise average yield by 0.57 bushel, about 2 percent (figured at the mean yield for 1956-84).

A warm August and cooler than normal average temperatures in May, July, and September are beneficial for the growth of spring wheat in the Lake States. This is a cooler region on average, and spring wheat seems to grow best at the monthly temperature norms. Acreage was not a significant determinant of yield in this region.

Estimated Rice Yield Equations

This section presents the estimated yield equations for the five major rice-producing States: Arkansas, Louisiana, California, Texas, and Mississippi. The data period, 1950-83, excludes the effects of the adoption of the high-yielding semidwarf varieties first introduced in 1983 in the southern area. However, technological gains of these semidwarfs will be considered when projecting rice yields beyond 1983.

Arkansas

The upward trend in yields since 1950 began to taper off by 1971. For this reason, we included the square root of the linear time trend to account for the yields increasing at a decreasing rate. A shift variable was added after 1962 to measure the marginal effect of widespread adoption of new herbicides and varietal improvements since that year. The equation suggests that about 600 pounds per acre can be attributed to these past innovations.

Farmers seed most of the acreage between April 10 and May 25, with harvest starting in mid-September, or 5-7 weeks after the time of first heading of the crop. Below-trend yields during the study period were induced by high July temperatures and excessive precipitation in August and September (equation 13). Sky cover helps yield by preventing water temperatures from exceeding the maximum desired threshhold of 85 degrees during the precanopy stage. Extreme heat may result in unfilled heads. The number of days with precipitation in August and September affects yield because heavy rain and winds prior to harvest may lodge grain, and grain germination may occur if harvest is delayed too long. A dummy variable for 1983 helps us estimate the effect of a heat wave when temperatures stayed above 100 degrees for 8 consecutive weeks in August and September. The following equation reports the coefficients for each effect in Arkansas.

$$
\begin{aligned}
RIYLD = -4819.1 &+ \underset{(6.25)}{1496.986*TSQRT} - \underset{(-5.50)}{1.62*HACRE} \\
&- \underset{(-2.07)}{74.3*P89} - \underset{(-1.57)}{40.3*TJL} + \underset{(1.93)}{146.8*SC56} \\
&+ \underset{(3.10)}{602.2*TREND62} - \underset{(-3.50)}{1040.7*D83} \qquad (13)
\end{aligned}
$$

$R^2 = 0.95$ DW = 1.96,

where RIYLD = Average rice yield, hundredweight per acre
TSQRT = Square root of time
HACRE = Harvested acres, thousands
P89 = Average days exceeding 0.1 inch rain, Aug.-Sept.
TJL = Average July temperature, degrees F.
SC56 = Percent of sky cover in May and June
TREND62 = (1962 = 0.5, 1963-83 = 1, 0 elsewhere)
D83 = Dummy variable, 1983 = 1, 0 elsewhere

Louisiana

Like Arkansas, yields in Louisiana had been increasing at a declining rate. Equation 14 shows that for each day in March and April where rainfall exceeds 0.1 inch, seeding will be delayed, and average yield will fall by 57 pounds per acre. The same variable for precipitation in May and June boosted average yield by 37.6 pounds.

$$\text{RIYLD} = -11393 \underset{(8.29)}{+388.4\text{*YEAR}} \underset{(-7.05)}{-2.46\text{*YEAR2}}$$

$$\underset{(-3.41)}{-57.2\text{*P34}} \underset{(1.93)}{+37.6\text{*P56}} \tag{14}$$

$R^2 = 0.94$ DW = 1.72,

where YEAR = Time trend (1950 = 50)
YEAR2 = Squared trend
P34 = Average no. days over 0.1 inch precipitation, Mar.-Apr.
P56 = Average no. days over 0.1 inch precipitation, May-June

California

Since 1975, rice yields in California have outpaced other areas because producers there have funded breeding research programs. This approach has been quite successful in developing new high-yielding varieties.

Warm June temperatures push along development of the crop, as shown in equation 15. The positive coefficient indicates a 61.5-pound-per-acre gain when average June temperature is 1 degree higher.

$$\text{RIYLD} = -13513 \underset{(12.35)}{+194.2\text{*YEAR75}}$$

$$\underset{(11.03)}{+1732.9\text{*TROOT74}} \underset{(2.70)}{+61.5\text{*TJU}} \tag{15}$$

$R^2 = 0.91$ DW = 1.69,

where YEAR75 = 0 before 1975, linear trend after
TROOT74 = Square root of time before 1975, 0 after
TJU = Average June temperature, degrees F.

Texas

An intercept shift starting in 1962 is an attempt to explain the impact of short season varieties which permit ratoon (shoots growing from the roots of a plant already cut down) and the harvest of a second crop. This practice is limited to the gulf coast area, as other regions become too cool in the late summer and fall.

Precipitation during April delays farmers' progress in the field, and excessive July and August temperatures reduce yield prospects (equation 16).

$$\text{RIYLD} = 14103.7 \underset{(11.25)}{+1430.2\text{*TREND62}} \underset{(-1.69)}{-1.11\text{*HACRE}}$$

$$\underset{(-1.27)}{-23.9\text{*PAP}} \underset{(-3.17)}{-125.9\text{*T78}} \tag{16}$$

$R^2 = 0.91$ DW = 1.73,

where TREND62 = 1962 = 0.5, 1963-83 = 1, 0 elsewhere
HACRE = Harvested acres, thousands
PAP = Average April precipitation, inches
T78 = Average July and August temperature, degrees F.

Mississippi

The ratio of lagged fertilizer price (ammonium sulfate) to farm price of rice is a measure of the profitability of growing rice. The elasticity for current prices is a 1.8-percent decrease in rice yield for every 10-percent increase in the price ratio.

March rainfall, days of precipitation in July and August, and July temperature are all negatively correlated to yield in this State, as shown in equation 17.

$$\text{RIYLD} = -38947 \underset{(-3.76)}{-632.2\text{*YEAR}} \underset{(4.15)}{+11366\text{*TSQRT}}$$

$$\underset{(-2.97)}{-51.92\text{*FERTP}} \underset{(-1.84)}{-25.5\text{*PMC}}$$

$$\underset{(-3.97)}{-109.9\text{*P89}} \underset{(-2.96)}{-80.3\text{*TJL}} \tag{17}$$

$R^2 = 0.93$ DW = 1.94,

where TSQRT = Square root of time
FERTP = Ammonium sulfate-rice farm price ratio
PMC = Average March precipitation, inches
P89 = Average no. days exceeding 0.1 inch precip., Aug.-Sept.
TJL = Average July temperature, degrees F.

Estimated Corn Yield Equations

The ordinary least squares estimates of corn yield response for the Corn Belt, Northern Plains, and Lake States are shown in this section along with a brief analysis of the results.

Corn Belt

As the highest yielding corn region, the Corn Belt produces 10 percent higher yields than the U.S. average. Acreage and output from this region supply over half of the U.S. total.

Equation 18 indicates that yields have risen 1.5 bushels per year because of technological improvements, about a 1.7-percent annual growth rate. This variable reflects a number of factors such as the introduction of new hybrids, pesticides, and cropping practices.

Planted acreage has, as expected, a significant inverse relationship with corn yields. The coefficient suggests that an additional million acres will lower yields by 1.2 bushels. The mean elasticity comes out as −0.34. However, if we compute at the current yields and acreage level, the elasticity will become slightly more inelastic.

The important weather influences are squared soil moisture, July precipitation, and July temperature. The Corn Belt receives by far the most rainfall of the major regions of study. One inch above normal July precipitation increased yields by 2.3 bushels, but 3.6 inches above normal reduced yields by 0.1 bushel. Maximum yields followed about 5.6 inches of rain during July. High temperatures in this month depress yields by 1.4 bushels for every degree above normal, which is 75.4 degrees.

An interaction term between total rainfall and nitrogen application was included in the equation. The term has the anticipated positive sign and an elasticity of 0.25, which means that as the amount of nitrogen fertilizer applied increases, and rainfall is constant, then corn yield will rise by this proportion.

We used a dummy variable for 1970 to account for the effect of the corn blight on yields in that year. The loss amounted to 15 bushels per acre, excluding other determining factors. The large acreage reduction due to the 1983 PIK program should have led to a yield increase, but the severe drought that summer lowered yields by 30 bushels, on average.

Northern Plains

Average yields are lower in the drier Northern Plains than in the Corn Belt. The Northern Plains averages 21.8 inches of rain each year, which explains the much larger effect of July precipitation. This region averages 2.9 inches of rainfall in July, almost 3 inches below the optimal amount. Just an additional inch during this time would improve the corn crop by 3.5 bushels per acre. The square of accumulated soil moisture is also highly significant.

Temperatures in July are not as influential here as in the Corn Belt. However, excessively high temperatures will reduce yields by as much as 0.4 bushel per degree above the normal 74.5 degrees.

The water-fertilizer interaction term is, again, a positive factor affecting corn yields. The mean elasticity derived from the equation is 0.16 and comparable in size to the Corn Belt response.

Acreage planted was included in preliminary regressions but was not significantly different from zero and was dropped from the equation. This near-zero calculation likely comes from the fact that a good portion of the corn acreage in this region is irrigated, making cropland less heterogeneous. Expansion onto dryland acreage is not a profitable option for many farmers. Nebraska and Kansas irrigate two-thirds of their corn, achieving 50-percent higher yields than unirrigated land. The technological trend variable increases by 2.1 bushels per year, a 3.2-percent rate.

Lake States

The upward trend in yield in the Lake States has averaged 2.4 bushels per year, a 3.1-percent rate, which is comparable to the other regions. July precipitation is again a key element in this region. The combined linear and nonlinear effects imply that 1.7 inches above the normal 3.6 inches usually received would be best. Since farmers plant a little later in the Lake States, August precipitation is important. An additional inch above normal for this month will raise output by 1.7 bushels per acre. The longrun average for August has been 3.6 inches.

The temperature for July is not as critical in the Lake States as in the Corn Belt because the Lake States are cooler, at 69.3 degrees compared with 75.4 degrees for the Corn Belt. August temperatures had the appropriate negative coefficient but were not statistically significant, so we dropped this variable from the final model specification.

Increasing the area planted by 1 million acres resulted in a 2.4-bushel decline in yield. The mean elasticity was calculated at −0.36. It seems that the yield response to a change in acreage is about as strong as in the Corn Belt.

In 1974, an abnormally late spring and an early frost contributed to a markedly lower yield in the

Lake States. For this region, a dummy variable was inserted into the equation for that year. Results suggest that the yield was 17 bushels below the amount normally predicted given the trend, acreage, and weather conditions.

Corn Belt Region (18)

$$
\begin{aligned}
\text{CORNYLD} = &-2929.5 + 1.54^*\text{YEAR} + 3.29^*\text{PJL} \\
&(-3.77) \quad (3.84) \quad (3.44) \\
&-0.99^*\text{PJL2} -0.08^*\text{SM2} -1.35^*\text{TJL} \\
&(-3.55) \quad (-2.53) \quad (-2.54) \\
&-0.74^*\text{TAU} -0.0009^*\text{PACRE} \\
&(-1.50) \quad (-2.05) \\
&+0.0054^*\text{RAINFERT} -15.0^*\text{D1970} \\
&(2.62) \quad (-3.01) \\
&-30.0^*\text{D1983} \\
&(-3.61)
\end{aligned}
$$

$R^2 = 0.97$ DW = 2.02

Northern Plains Region (19)

$$
\begin{aligned}
\text{CORNYLD} = &-3661.4 + 1.89^*\text{YEAR} + 5.15^*\text{PJL} \\
&(-4.42) \quad (4.44) \quad (3.91) \\
&-1.59^*\text{PJL2} -0.44^*\text{SM2} -0.75^*\text{TJL} \\
&(-2.05) \quad (-2.36) \quad (-1.52) \\
&+0.007^*\text{RAINFERT} \\
&(1.75)
\end{aligned}
$$

$R^2 = 0.96$ DW = 2.43

Lake States Region (20)

$$
\begin{aligned}
\text{CORNYLD} = &-4571.8 + 2.38^*\text{YEAR} + 5.85^*\text{PJL} \\
&(-10.25) \quad (10.24) \quad (3.69) \\
&-3.31^*\text{PJL2} + 1.74^*\text{PAU} -0.51^*\text{TJL} \\
&(-2.06) \quad (1.51) \quad (-0.91) \\
&-0.0024^*\text{PACRE} -16.9^*\text{D1974} \\
&(-2.08) \quad (-2.66)
\end{aligned}
$$

$R^2 = 0.91$ DW = 2.30,

where CORNYLD = Corn yield, bushels per acre
YEAR = Technological trend (1956 = 1956)
PJL = Deviation from average July precipitation, inches
PJL2 = PJL squared, inches
PAU = Deviation from average August precip., inches
PAU2 = PAU squared, inches
TJL = Deviation from average July temperature, degrees F.
TAU = Deviation from average August temperature, degrees F.
SM2 = Squared deviation from average soil moisture, Sept.-June, inches
PACRE = Planted acreage, thousands
RAINFERT = Interaction between annual precipitation and nitrogen fertilizer applied
D1970 = Dummy variable for 1970 corn blight
D1974 = Dummy variable for early freeze and late spring
D1983 = Dummy variable for 1983 PIK program and drought

Estimated Sorghum Yield Equations

Equations 21-23 represent the least-squares estimates for grain sorghum yields. The historical data for yield, acreage, and production for the three regions are in appendix tables 17-19.

Northern Plains

At 1.2 bushels per acre per year, the trend in sorghum yield is highest in this region, and partly explains the shift in production to the Northern Plains. Although no temperature variables were significant, precipitation for June and July had the expected positive sign. Soil moisture exhibits a positive response over lower amounts but becomes negative for above-normal levels. Fertilizer price has the correct negative coefficient, and the elasticity is -0.19. The acreage effect was not significant in this or other regions.

Southern Plains

Yield advances have been slowest in Texas and Oklahoma at an annual increment of 0.3 bushel per acre (equation 22). The effect of temperature in April confirms the importance of being able to plant early in the season. Higher than normal temperatures allow for good starts for the young sorghum plants. However, as the crop matures, the expected negative effects of temperatures during May, June, and August are apparent. Soil moisture early in the season benefits yield, as evidenced by the estimated 0.3-bushel increase in sorghum yield per inch of soil moisture. The price elasticity of fertilizer is slightly larger in the Southern Plains, at −0.24.

Corn Belt

The productivity growth for sorghum in this region has been rising, on average, by 1.1 bushels per year (equation 23). The June precipitation coefficent implies that for 1 inch above the longrun mean, yield rises by 1.4 bushels. Likewise, soil moisture improves yield by 0.6 bushel per additional inch of rain. Abnormally warm temperatures during July and August inhibit plant development and reduce yields by 1.5 and 2.8 bushels, respectively, for each degree above normal. The effect of September temperature depicts a curved function, and yield increases at a decreasing rate as the warmer temperatures prolong the growing season and aid harvest.

Northern Plains Region (21)

$$
\begin{aligned}
SORYLD = & -2364.0 + 1.23*YEAR + 0.16*PJU \\
& (-7.04) \quad (7.29) \quad (0.14) \\
& + 8.0*PJL - 2.66*PJL2 - 0.60*SM2 \\
& (6.04) \quad (-2.85) \quad (-3.05) \\
& - 1.49*RFERTP \\
& (-0.17)
\end{aligned}
$$

$R^2 = 0.84$ DW = 2.54

Southern Plains Region (22)

$$
\begin{aligned}
SORYLD = & -574.6 + 0.32*YEAR + 0.61*PAP2 \\
& (-2.55) \quad (2.81) \quad (-2.33) \\
& - 2.26*PJL + 0.30*SM2 + 0.68*TAP \\
& (-2.30) \quad (1.60) \quad (2.14) \\
& - 1.21*TMAY - 1.56*TJU - 1.65*TAU \\
& (-2.28) \quad (-2.96) \quad (-3.20) \\
& - 8.76*RFERTP \\
& (-1.56)
\end{aligned}
$$

$R^2 = 0.89$ DW = 2.54

Corn Belt Region (23)

$$
\begin{aligned}
SORYLD = & -2189.9 + 1.14*YEAR + 1.40*PJU2 \\
& (-6.25) \quad (6.50) \quad (1.40) \\
& + 0.60*SM - 1.50*TJL - 2.84*TAU \\
& (1.75) \quad (-2.24) \quad (-3.96) \\
& + 1.60*TSP - 0.37*TSP2 \\
& (2.49) \quad (-1.79)
\end{aligned}
$$

$R^2 = 0.84$ DW = 2.34,

where YEAR = Technological trend (1956 = 1956)
PAP2 = Squared deviation April precipitation, inches
PJU = Deviation from average June precipitation, inches
PJU2 = PJU squared, inches
PJL = Deviation from average July precipitation, inches
SM = Deviation from average soil moisture, inches
SM2 = SM squared, inches
TAP = Deviation from average April temperature, degrees F.
TMAY = Deviation from average May temperature, degrees F.
TJU = Deviation from average June temperature, degrees F.
TJL = Deviation from average July temperature, degrees F.
TAU = Deviation from average August temperature, degrees F.
TSP = Deviation from average September temperature, degrees F.
TSP2 = TSP squared, degrees F.
RFERTP = Real fertilizer price index

Estimated Barley Yield Equations

Regional barley yield equations are reported below in equations 24-27 with an interpretation of the estimated coefficients.

Pacific Region

The Pacific region has the highest yielding barley acreage in the Nation. Nearly all of the barley raised in California is planted in the fall and is intended for feed. Some malting barley is produced in Oregon and Washington. The 1982 Census of Agriculture reports that about 56 percent of the barley acreage in California was irrigated in 1978, with average per acre yields of 55 bushels. This compares with a 36-bushel-per-acre yield on unirrigated land.

We included a technological trend variable to capture the impact of higher rates of fertilization and herbicide application, along with the development of new varieties. The critical months for crop development are earlier in the West than in the Midwest. Precipitation during March and April have a significant influence on yield. One degree above average June temperatures reduced average yields by 1.3 bushels per acre.

Lake States

Barley yield increases by 0.73 bushel per year, and by 2.75 bushels for each inch above average in April. An inch deviation above the longrun average of 3.8 inches of rain during June is expected to improve the crop outlook by 0.9 bushel. Equation 25 also contains June and July temperatures. An index for real fertilizer prices has also been included.

Northern Plains

The specification of this equation is similar to the one used for the Lake States region. An inch above normal June precipitation increases barley yield by 1.2 bushels per acre. A degree above normal temperature in May results in a yield 0.3 bushel higher, but excessive June and July temperatures reduce yield by 0.6 and 1.5 bushels, respectively. Since this is mostly a region where malting barley is produced, average yields are lowest here.

Mountain Region

The Mountain region encompasses all of Idaho, Montana, Wyoming, Colorado, Utah, Nevada, New Mexico, and Arizona. It is the driest region, with an average annual rainfall of 13.5 inches compared with 29.6, 27.8, and 21.8 inches for the Lake States, Pacific States, and the Northern Plains, respectively. One might expect a slightly larger yield response to increased precipitation. May precipitation and June and July temperatures are the seasonal determinants of barley yields in the Mountain region. The soil moisture index is also expected to have a positive effect on yield.

The technological trend coefficient indicates similar yield increases over time among the four regions. An annual increment of about 0.8 bushel predominates for all regions.

The equations generally substantiate the hypothesis that barley responds best to cooler temperatures and adequate, but not excessive, moisture levels. Negative coefficients for the temperature variables, positive coefficients on precipitation, and negative signs on the squared terms bear this out.

Fertilizer price deflated by the Consumer Price Index was statistically significant in all regions except the Pacific region. All have the expected negative coefficient that an input price would have on production. The equations suggest that a 1-percent rise in the ratio would reduce yields by about 0.19 percent.

Pacific Region (24)

$$\begin{aligned} \text{BARYLD} = & \underset{(-12.1)}{-1449.2} \; \underset{(12.5)}{+0.76^*\text{YEAR}} \; \underset{(0.65)}{+0.47^*\text{PAP}} \\ & \underset{(-2.91)}{-1.65^*\text{PAP2}} \; \underset{(1.23)}{+0.49^*\text{PMC}} \\ & \underset{(-5.21)}{-1.62^*\text{TJU}} \; \underset{(2.15)}{+0.29^*\text{TJU2}} \end{aligned}$$

$R^2 = 0.94$ DW = 1.49

Lake States Region (25)

$$\begin{aligned} \text{BARYLD} = & \underset{(-7.68)}{-1684.6} \; \underset{(8.00)}{+0.73^*\text{YEAR}} \; \underset{(1.73)}{+2.75^*\text{PAP}} \\ & \underset{(1.01)}{+0.90^*\text{PJU}} \; \underset{(1.95)}{+0.18^*\text{TJU2}} \\ & \underset{(-1.92)}{-0.73^*\text{TJL}} \; \underset{(-1.63)}{-9.28^*\text{RFERTP}} \end{aligned}$$

$R^2 = 0.88$ DW = 1.95

Northern Plains Region (26)

$$\begin{aligned} \text{BARYLD} = & \underset{(-10.8)}{-1903} \; \underset{(11.2)}{+0.98^*\text{YEAR}} \; \underset{(4.81)}{+2.44^*\text{PJU}} \\ & \underset{(-3.19)}{-1.27^*\text{PJU2}} \; \underset{(2.40)}{+2.03^*\text{PJL}} \; \underset{(-4.14)}{-2.09^*\text{PJL2}} \\ & \underset{(1.73)}{-0.33^*\text{TMAY}} \; \underset{(-2.56)}{-0.62^*\text{TJU}} \\ & \underset{(-4.90)}{-1.52^*\text{TJL}} \; \underset{(-1.38)}{-6.04^*\text{RFERTP}} \end{aligned}$$

$R^2 = 0.96$ DW = 2.39

Mountain Region (27)

$$\begin{aligned} \text{BARYLD} = & \underset{(-9.99)}{-1631} \; \underset{(10.5)}{+0.86^*\text{YEAR}} \; \underset{(2.47)}{+3.78^*\text{PMAY}} \\ & \underset{(-1.43)}{-0.50^*\text{SM2}} \; \underset{(1.13)}{+0.41^*\text{TMAY}} \; \underset{(-1.45)}{-0.48^*\text{TJU}} \end{aligned}$$

$$-1.04*TJL - 0.0045*HACRE - 11.0*RFERTP$$
$$(-1.76) \quad (-3.12) \quad (-2.71)$$

$R^2 = 0.94$ DW = 1.72,

where YEAR = Technological trend (1956 = 1956)
PMC = Deviation from average March precipitation, inches
PAP = Deviation from April precipitation, inches
PAP2 = PAP squared, inches
PMAY = Deviation from May precipitation, inches
PJU = Deviation from June precipitation, inches
PJU2 = PJU squared, inches
PJL = Deviation from average July precipitation, inches
PJL2 = PJL squared, inches
SM2 = Squared deviation from average soil moisture, June-Mar., inches
TMC = Deviation from average March temperature, degrees F.
TMAY = Deviation from average May temperature, degrees F.
TJU = Deviation from average June temperature, degrees F.
TJL = Deviation from average July temperature, degrees F.
TAU = Deviation from average August temperature, degrees F.
RFERTP = Real fertilizer price index
HACRE = Harvested acres, thousands

Estimated Oats Yield Equations

The Corn Belt, Lake States, and Northern Plains regions account for about 80 percent of U.S. oats production. While there are similar yield response patterns in these regions such as the increase in yields over time, considerable differences exist in the growth rate in yields over time and the relative effects of fertilizer prices, acreage, and weather variables (soil moisture, monthly precipitation, and temperature).

Corn Belt

Oats yields grew 0.25 bushel an acre per year since 1956, the smallest rate among the primary production regions. The average oats yield is inversely related to acreage; yield increases (decreases) by about 1 bushel an acre as acreage decreases (increases) by 625,000 acres, which is a 1-percent increase in acreage resulting in a 0.14-percent decline in yield. As expected, the higher the fertilizer prices, the lower the oats yields because less nitrogen is applied.

Soil moisture (measured as the accumulated precipitation from September through May) normally averages 33.4 inches in this area, which is quite adequate for oats production. Excessive soil moisture tends to delay the planting schedule and to reduce yields. Above-normal precipitation in July shows a positive effect on oats yields at the filling stage. Warmer than normal temperatures in May and July lower yields.

Lake States

The increase in oats yield due to technological improvements has been 0.4 bushel per year (equation 29). The growing season begins later and ends sooner in Minnesota than in other producing States. Weather influences this region differently with June being the important time for rainfall. High temperatures during June and July stress oats crops and reduce yields. Excess soil moisture before planting results in lower yields, as do increases in fertilizer input costs.

Northern Plains

Equation 30 is similar in structure to the other regions, but a few differences ought to be emphasized. It should be noted that the trend coefficient is much larger in the Northern Plains than in the other regions.

The yield response is more sensitive to climatic change. It is drier on average, receiving annual precipitation of 21.8 inches compared with 29.6 and 37.7 inches for the Lake States and Corn Belt, respectively. Average yields in this region are much lower than in other regions as a consequence. This explains why the soil moisture coefficient in this equation has a positive effect (up to 4 inches above average), and the coefficient for June precipitation is so much larger, nearly three times the coefficient of the Lake States. The effect of July temperatures is twice as high in this region as in the Lake States.

Corn Belt Region (28)

$$OATYLD = -440.2 + 0.26*YEAR - 0.0016*HACRE$$
$$(-1.67) \quad (1.92) \quad (-3.79)$$

$$+ 0.72*PJL + 0.24*TAP - 0.20*TMAY$$
$$(2.03) \quad (1.34) \quad (-1.31)$$

$$-0.28{*}SM \; -0.05{*}SM2 \; -2.7{*}RFERTP$$
$$(-1.98) \quad (-2.94) \quad (-0.74)$$

$R^2 = 0.92 \quad DW = 2.99$

Lake States Region (29)

$$OATYLD = -745.7 + 0.41{*}YEAR + 1.3{*}PJU$$
$$(-3.77) \quad (4.11) \quad (2.10)$$

$$-0.74{*}TJU \; -0.68{*}TJL \; -10.4{*}RFERTP$$
$$(-2.76) \quad (-1.88) \quad (-2.45)$$

$$-0.72{*}SM + 0.11{*}SM2$$
$$(-3.23) \quad (1.60)$$

$R^2 = 0.79 \quad DW = 1.88$

Northern Plains Region (30)

$$OATYLD = -1090 + 0.58{*}YEAR + 3.74{*}PJU$$
$$(-5.74) \quad (4.27) \quad (4.92)$$

$$-1.01{*}PJU2 \; -1.34{*}PJL2 + 1.26{*}PAU$$
$$(-1.98) \quad (-2.45) \quad (1.69)$$

$$+0.60{*}TMAY \; -1.51{*}TJL \; -12.9{*}RFERTP$$
$$(2.16) \quad (-4.48) \quad (-2.69)$$

$$+1.34{*}SM \; -0.16{*}SM2$$
$$(3.03) \quad (-1.21)$$

$R^2 = 0.92 \quad DW = 2.59,$

where YEAR = Technological trend (1956 = 1956)
HACRE = Harvested acres, thousands
PJU = Deviation from average June precipitation, inches
PJU2 = PJU squared, inches
PJL = Deviation from average July precipitation, inches
PAU = Deviation from average August precipitation, inches
TAP = Deviation from average April temperature, degrees F.
TMAY = Deviation from average May temperature, degrees F.
TJU = Deviation from average June temperature, degrees F.
TJL = Deviation from average July temperature, degrees F.
RFERTP = Lagged real fertilizer price index
SM = Deviation from average soil moisture, Sept.-May, inches
SM2 = SM squared, inches

Implications for Acreage Reduction Programs

This section highlights effects of crop acreage on grain yields and discusses implications for the ARP.

Yield-Acreage Elasticities

Average crop yields tend to increase on remaining acres as marginal land is removed from production or as the size of farm becomes more manageable. This means that a percentage reduction in acreage will not be matched by a corresponding percentage reduction in crop production. Estimates of the actual production decline follow.

Wheat. The inverse relationship between acreage and average yield can be illustrated by calculating elasticities of yield (Ey:A) and production (Eq:A) associated with a 1-percent change in acreage, where Eq:A = 1 + Ey:A.[5] The elasticities in the Northern Plains, for example, can be computed from: (1) the coefficients of the acreage variable (−0.0013 for winter wheat and -0.0005 for spring wheat); (2) average yields of 37.2 bushels for winter wheat and 32.5 bushels for spring wheat; and (3) harvested acreage of 15.7 million acres for winter wheat and 10.2 million planted acres for spring wheat. That is:

Winter wheat

$$Ey{:}A = \frac{-0.0013 / 1}{37.2 / 15{,}700} = -0.55$$

$$Eq{:}A = 1 - 0.55 = 0.45$$

Spring wheat

$$Ey{:}A = \frac{-0.0005 / 1}{32.5 / 10{,}213} = -0.16$$

$$Eq{:}A = 1 - 0.16 = 0.84$$

All wheat

$$Ey{:}A = 0.63\,(-0.55) + 0.37\,(-0.16) = -0.41$$

$$Eq{:}A = 1 - 0.41 = 0.59,$$

where 0.63 and 0.37 are the share of winter and spring wheat in the Northern Plains, respectively.

[5]The authors wish to thank Sam Evans of ERS for calling this relationship to our attention.

Table 1 shows the elasticities for yield and production with respect to a 1-percent change in wheat acreage in the major production regions. The acreage variable is not statistically significant in the Southern Plains and Lake States.

The degree of this inverse relationship varies among regions. For all wheat, the elasticity (in absolute value) ranges from 0.09 in the Mountain region to 0.41 in the Northern Plains. For example, the −0.41 elasticity for yield in the Northern Plains means a 10-percent reduction in acreage would raise wheat yields on the remaining acres by 4.1 percent, thereby reducing wheat production by only 5.9 percent (at 100-percent program compliance). In the 1986 program, wheat production in this region would have declined about 13 percent if about 90 percent of the base acreage complied with the program, which requires a 25-percent acreage limitation of the base. Some winter wheat farmers had set aside more than 25 percent of their base, and this would have further reduced wheat production. However, slippage of the ARP may prove to be even larger than what is indicated here since participants and nonparticipants alike may intensify their use of nonland inputs to boost wheat yields, and nonparticipants may expand their acreage seeded to wheat.

The yield elasticity (in absolute value) in the Northern Plains was higher than that in the Corn Belt because: (1) participation in the Government wheat program was generally highest in the Northern Plains; (2) the quality of soil was less well suited for crops other than wheat in the Northern Plains and was more prone to a greater yield response for the removal of marginal land from production; and

Table 1—Acreage elasticities for wheat yields and production

Region	Wheat class	Elasticities for— Yield (Ey:A)	Production (Eq:A)
Northern Plains	Winter	−0.55	0.45
	Spring	−.16	.84
	All	−.41	.59
Mountain region	Winter	−.12	.88
	Spring	—	—
	All	−.09	.91
Pacific region	Winter	—	—
	Spring	−.07	.93
	All	−.23	.77
Corn Belt	Winter	−.23	.77

— = not applicable.

(3) irrigation on wheat land was more common in the Northern Plains than in the Corn Belt, consequently enlarging the yield response from the removal of dryland. According to the 1982 Census of Agriculture, the average wheat yield for irrigated land was 64.3 bushels an acre compared with 31.8 bushels on dryland. Therefore, the yield elasticity in the Northern Plains turned out to be twice as much as that in the Corn Belt.

Wheat yield elasticity regarding acreage was smaller than the elasticity for corn in the Corn Belt. We estimated yield elasticity regarding acreage for corn in the Corn Belt at -0.3, compared with the -0.23 yield elasticity for wheat.

Rice. Of the five major rice-producing States included in this study, the acreage variable was statistically significant only in Texas and Arkansas. This may be related to the fact that farmers irrigate 100 percent of the acres planted to rice, and land devoted to rice production tended to be more homogeneous and had to be level to allow irrigation. It is conceivable that acreage increases had negative impacts on rice yields in Texas and Arkansas due to limited capital and other resource constraints in the short run, decreases in the soybean-rice rotation ratio, and conversion of less productive land into rice production.

Following the same procedure as illustrated for wheat, elasticities of yield (Ey:A) and production (Eq:A) associated with a 1-percent change in harvested acreage are computed as follows:

Arkansas

$$Ey{:}A = \frac{-1.6168 \; / \; 1}{5{,}150 \; / \; 1{,}330} = -0.42$$

$$Eq{:}A = 1 - 0.42 = 0.58$$

Texas

$$Ey{:}A = \frac{-1.1078 \; / \; 1}{5{,}250 \; / \; 474} = -0.10$$

$$Eq{:}A = 1 - 0.10 = 0.90$$

The computed elasticities of acreage show that rice yields tended to increase 4.2 percent for a 10-percent decrease in harvested acreage in Arkansas. As a result, this same acreage decline corresponds to a 5.8-percent decline in rice production. The yield elasticity (in absolute value) is considerably smaller in Texas, making production control through acreage reduction more effective.

Corn. Following the same procedure discussed previously, yield and production elasticities associated with a 1-percent change in planted acreage, respectively, are shown for the Corn Belt and Lake States as follows:

Corn Belt Region

$$Ey{:}A = \frac{-0.91 / 1}{112.4 / 37.1} = -0.30$$

$$Eq{:}A = 1 - 0.30 = 0.70$$

Lake States Region

$$Ey{:}A = \frac{-2.40 / 1}{101.8 / 14.5} = -0.34$$

$$Eq{:}A = 1 - 0.34 = 0.66$$

The computed acreage elasticities indicate that corn yields tended to increase 3 percent for a 10-percent decrease in acreage planted to corn in the Corn Belt, which resulted in a 7-percent decline in production. The slippage of ARP's appeared to be slightly more in the Lake States. Corn yields tended to increase 3.4 percent for a 10-percent decrease in acreage planted in this region. Overall corn production declined, however, by 6.6 percent.

Sorghum. Acreage was not a significant determinant of sorghum yield for any of the major production regions. Therefore, removing land from production had no measurable effect on sorghum yields.

Barley. The acreage variable was statistically significant only in the Mountain Region, where removing 1 million acres of cropland from production boosted barley yield by 4.4 bushels. Yield and production elasticities of a 1-percent decline in harvested acreage are computed below:

Mountain

$$Ey{:}A = \frac{-0.0044 / 1}{54.6 / 3{,}510} = -0.28$$

$$Eq{:}A = 1 - 0.28 = 0.72$$

The elasticities mean that barley yields tended to increase 2.8 percent for a 10-percent decrease in acreage planted to barley in the Mountain States. As a result, a decline in barley production of 7.2 percent for the region occurs, so provisions for restrictions on barley acreage appear to be relatively effective when compared with other grain crops.

Oats. A removal of 1 million acres of cropland from oats production increased average oats yield by an estimated 1.6 bushels an acre in the Corn Belt. Based on this relationship and data on yield and harvested acreage in recent years, yield and production elasticities with respect to a 1-percent change in harvested acreage in the Corn Belt are computed as follows:

$$Ey{:}A = \frac{-0.0016 / 1}{58.9 / 2{,}300} = -0.06$$

$$Eq{:}A = 1 - 0.06 = 0.94$$

Harvested acreage was used instead of planted acreage so that the elasticity could be measured without being distorted by any effects from the use of oats as a cover crop.

Oats yield response to a 10-percent change in harvested acreage ranks among the lowest of the major grains included in this study. There are several possible explanations. Acreage may be less variable itself because farmers grow oats primarily for feeding to their own livestock. Up to 65 percent of oats production is used on the farm, and the remainder is sold. Since they are chiefly concerned with obtaining an adequate supply for their own use, farmers do not pull out oats acreage because of feed program changes. However, when higher quality acreage that would have gone into the production of other grains is diverted, some yield improvement may occur if more oats are planted on this better land. In part because of the above reason, the relationship between yield and acreage was positive in the Northern Plains.

$$Ey{:}A = \frac{0.0040 / 1}{48.6 / 4{,}100} = +0.34$$

$$Eq{:}A = 1 + 0.34 = 1.34$$

For every 10-percent increase in acreage, total oats production increased by 13.4 percent.

Effects of the 1986 Programs

Production efficiency for most program crops was probably enhanced as farmers removed their marginal, low-yielding land from production for complying with the ARP's. The magnitude of yield increases in response to a 10-percent reduction in acreage are as follows: (1) wheat, 2.2 percent; (2) rice, 2 percent; (3) corn, 3 percent; (4) sorghum, no measurable effect; (5) barley, 1 percent; and (6) oats, 0.2 percent.

We estimated the effects of diverting marginal cropland under ARP on national average yields in 1986 compared with no ARP: (1) wheat, 6.6 percent, an increment of 2.5 bushels an acre; (2) rice, 10.1 percent, an increment of 580 pounds per acre; (3) corn, 5 percent, an increment of 5.7 bushels higher; (4) sorghum, no effect; (5) barley, 1.4 percent, up 0.7 bushel; and (6) oats, 0.1 percent, or 0.1-bushel increment.

Crop Yield Projections

Tables 2-8 show the projected trend yields for each commodity, by region. The underlying assumptions in the tables are that the precipitation and temperature variables are at their longrun average and that each region maintains a constant share of U.S. acreage as in recent years.

Wheat

We foresee a yield of over 42 bushels an acre by 1990, 12.3 percent higher than the 1985 yield of 37.5 bushels. If land harvested nationwide in 1990 is 66 million acres, we project wheat production to be up by 350 million bushels, 14 percent higher than U.S. production in 1985.

Rice

We calculated the projections for rice in tables 3 and 4 by using the estimated equations 13-17. However, to predict the effect of adopting high-yielding semidwarf varieties, we used projections of the adoption rate for each State and the yield difference between the Lemont and Newbonnet varieties and the traditional varieties to derive adjusted yield projections. We calculated yield differences resulting from the adoption of semidwarfs by multiplying the projected adoption rates by yield difference, the second column of the lower portion of table 3. The estimates employed here are outlined further by Ito, Grant, and Rister (16).

The average U.S. rice yield approaches 61.6 hundredweight (cwt) per acre by 1990. This is 13 percent higher than the 1985 average yield.

Corn

Table 5 shows that from 1985's average of 118 bushels per acre, yield is expected to increase to about 132 bushels by 1990, a 12-percent rise. Although we project acreage will continue to fall, yield growth will offset much of the decline. This may result in crops not substantially smaller than 1985's record 8.87-billion bushel crop.

Table 2—All-wheat yield projections, 1987-90

Region	1987	1988	1989	1990
		Bushels		
Northern Plains	38.4	39.7	40.8	41.5
Southern Plains	30.4	30.7	31.1	31.4
Mountain region	37.0	37.5	38.1	38.6
Pacific region	66.6	67.9	69.3	70.6
Corn Belt	44.7	45.2	45.9	46.4
Lake States	41.2	41.9	42.5	43.2
United States	40.0	40.7	41.6	42.1

Table 3—Projected adoption rates of high-yielding rice semidwarfs, 1987-90

State	1987	1988	1989	1990
		Percent		
Arkansas	0.70	0.76	0.80	0.83
Louisiana	.60	.68	.75	.80
Texas	.86	.92	.95	.97
Mississippi	.70	.76	.80	.83
		Yield difference from adopting semidwarfs		
		Pounds/acres		
Arkansas	735	798	840	872
Louisiana	720	816	900	960
Texas	1,290	1,380	1,425	1,455
Mississippi	770	836	880	913

Source: (16).

Table 4—Rice yield projections, 1987-90

State	1987	1988	1989	1990
		Trend yield		
		Pounds		
Arkansas	5,293	5,366	5,446	5,457
Louisana	3,733	3,692	3,645	3,593
California	7,814	8,009	8,203	8,397
Texas	4,671	4,557	4,557	4,540
Mississippi	3,890	3,865	3,837	3,806
		Adjusted yield		
		Pounds		
Arkansas	6,028	6,164	6,286	6,329
Louisana	4,453	4,508	4,545	4,553
California	7,814	8,009	8,203	8,397
Texas	5,961	5,937	5,982	5,995
Mississippi	4,660	4,701	4,717	4,719
United States	5,890	6,007	6,105	6,158

Sorghum

Sorghum yield is projected to reach 71 bushels by 1990, up from 66.8 bushels in 1985. An upward trend in acreage toward 15.6 million acres will generate production of at least 1.1 billion bushels, about equal to the record 1985 output.

Barley

By 1990, U.S. barley yield will approach 59 bushels per acre. Assuming that total harvested acreage falls to 10.3 million acres, we anticipate that barley production will gradually fall to just above 605 million bushels, 3 percent higher than the 1985 crop.

Oats

The projected oats yield for 1990 is 62.9 bushels per acre. A slow drop in acreage to 8.8 million acres harvested will probably produce a total U.S. output near 553 million bushels, which is less than 5 percent higher than the 1985 level.

Table 5—Corn yield projections, 1987-90

Region	1987	1988	1989	1990
		Bushels		
Corn Belt	131.0	133.7	136.2	138.1
Northern Plains	111.2	113.1	115.0	116.9
Lake States	118.5	121.8	125.2	128.0
United States	124.3	127.0	129.6	131.7

Table 6—Sorghum yield projections, 1987-90

Region	1987	1988	1989	1990
		Bushels		
Northern Plains	74.9	76.2	77.4	78.6
Corn Belt	79.6	80.8	82.0	83.2
Southern Plains	54.4	54.7	55.0	55.3
United States	68.4	69.3	70.2	71.1

Table 7—Barley yield projections, 1987-90

Region	1987	1988	1989	1990
		Bushels		
Pacific region	64.8	65.6	66.4	67.2
Lake States	56.9	57.8	58.7	59.5
Northern Plains	50.7	51.6	52.4	53.3
Mountain region	56.4	57.9	59.1	60.1
United States	55.7	56.9	58.0	58.8

Table 8—Oats yield projections, 1987-90

Region	1987	1988	1989	1990
		Bushels		
Corn Belt	65.2	65.5	65.8	66.0
Lake States	62.4	62.8	63.2	63.6
Northern Plains	58.2	59.0	59.9	60.9
United States	61.1	61.6	62.2	62.9

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Appendix table 1—Wheat acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	------- *Million acres* -------		*Bushels*	*Million bushels*
1956	60.7	49.8	20.2	1,005
1957	49.8	43.8	21.8	956
1958	56.0	53.0	27.5	1,457
1959	56.7	51.7	21.6	1,118
1960	54.9	51.9	26.1	1,355
1961	55.7	51.6	23.9	1,232
1962	49.3	43.7	25.0	1,092
1963	53.4	45.5	25.2	1,147
1964	55.7	49.8	25.8	1,283
1965	57.4	49.6	26.5	1,316
1966	54.1	49.6	26.3	1,305
1967	67.3	58.4	25.8	1,508
1968	61.9	54.8	28.4	1,557
1969	53.5	47.1	30.6	1,443
1970	48.7	43.6	31.0	1,352
1971	53.8	47.7	33.9	1,619
1972	54.9	47.3	32.7	1,546
1973	59.3	54.1	31.6	1,711
1974	71.0	65.4	27.3	1,782
1975	74.9	69.5	30.6	2,127
1976	80.4	70.9	30.3	2,149
1977	75.4	66.7	30.7	2,046
1978	66.0	56.5	31.4	1,776
1979	71.4	62.5	34.2	2,134
1980	80.8	71.1	33.5	2,381
1981	88.3	80.6	34.5	2,785
1982	86.2	77.9	35.5	2,765
1983	76.4	61.4	39.4	2,420
1984	79.2	66.9	38.8	2,595
1985	75.6	64.7	37.5	2,425
1986	72.0	60.7	34.4	2,087

Source: (*36*).

Appendix table 2—Northern Plains wheat acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	------- *Million acres* -------		*Bushels*	*Million bushels*
1956	24.7	21.1	16.2	343.3
1957	19.1	16.5	20.5	338.1
1958	23.3	22.6	27.2	613.9
1959	23.5	21.9	18.1	395.4
1960	23.1	22.2	25.0	554.5
1961	23.3	21.6	21.1	455.5
1962	20.7	19.0	23.8	452.0
1963	21.9	19.2	21.0	402.0
1964	22.5	20.9	22.4	469.0
1965	23.8	21.7	23.3	505.7
1966	23.0	21.8	22.6	493.4
1967	27.6	25.0	22.5	563.3
1968	25.9	23.3	27.2	632.2
1969	22.9	21.4	29.9	639.8
1970	20.9	19.9	29.5	586.4
1971	23.8	22.5	33.8	771.9
1972	22.7	21.3	31.8	679.0
1973	25.1	24.2	32.2	780.3
1974	28.8	27.9	24.5	685.4
1975	29.8	28.3	27.4	776.1
1976	32.2	28.9	26.3	760.8
1977	30.1	27.3	27.4	750.0
1978	27.5	25.2	29.1	733.7
1979	28.5	25.8	31.4	809.4
1980	31.8	27.7	27.8	770.4
1981	33.2	30.6	27.1	830.1
1982	31.6	29.9	32.9	983.4
1983	26.5	23.0	36.1	831.0
1984	29.3	25.8	35.8	922.4

Source: (*37*).

Appendix table 3—Southern Plains wheat acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	------- *Million acres* -------		*Bushels*	*Million bushels*
1956	9.0	6.3	15.2	95.7
1957	7.4	5.8	13.3	76.7
1958	8.4	7.7	24.1	184.8
1959	9.0	7.8	18.8	145.5
1960	9.0	8.2	24.3	200.1
1961	8.9	8.3	23.6	195.7
1962	7.8	6.5	17.7	114.8
1963	8.8	6.0	20.0	120.9
1964	9.1	7.4	21.7	161.5
1965	9.8	8.2	25.5	209.3
1966	9.5	7.9	21.6	171.4
1967	12.1	8.5	16.6	141.9
1968	11.1	9.2	22.6	208.4
1969	9.6	7.2	26.4	190.7
1970	8.6	6.2	25.3	155.8
1971	8.6	5.1	20.3	103.4
1972	9.8	5.9	22.7	133.7
1973	10.6	8.7	29.6	256.4
1974	12.6	9.7	19.3	187.2
1975	13.9	12.4	23.5	291.9
1976	14.3	11.0	23.2	254.6
1977	14.1	11.2	26.2	293.0
1978	12.7	8.1	24.7	199.8
1979	12.8	10.3	34.4	354.6
1980	14.3	11.7	27.8	325.0
1981	15.7	12.9	27.5	356.2
1982	16.2	12.9	28.8	371.7
1983	15.6	8.9	35.0	311.5
1984	15.1	10.3	33.1	340.8

Source: (*37*).

Appendix table 4—Mountain States wheat acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	------- *Million acres* -------		*Bushels*	*Million bushels*
1956	11.5	8.4	19.2	160.6
1957	8.5	7.6	23.9	182.6
1958	9.8	9.1	25.6	233.6
1959	9.1	8.4	22.9	192.0
1960	8.7	8.2	23.9	196.7
1961	8.8	7.9	20.6	163.6
1962	8.5	7.0	23.4	163.9
1963	8.9	7.3	22.9	167.6
1964	9.0	7.3	24.5	178.3
1965	9.6	7.2	26.4	189.5
1966	8.6	7.8	25.4	199.7
1967	10.4	8.6	27.3	235.7
1968	9.9	8.5	28.6	244.0
1969	8.7	7.5	27.8	206.8
1970	7.9	7.2	30.0	214.7
1971	9.0	8.2	30.7	251.8
1972	8.7	7.7	29.6	226.4
1973	9.4	8.8	27.9	244.0
1974	11.0	10.2	28.1	287.8
1975	11.2	10.2	31.5	322.7
1976	12.1	10.7	32.6	349.3
1977	11.3	10.1	27.6	278.1
1978	11.0	9.8	32.0	313.4
1979	12.2	10.4	28.4	294.6
1980	12.7	11.4	32.8	373.2
1981	12.7	11.8	34.2	403.2
1982	12.2	11.1	36.6	405.4
1983	11.7	9.9	39.7	393.7
1984	11.9	10.3	33.3	344.2

Source: (*37*).

Appendix table 5—Pacific States wheat acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	Million acres		*Bushels*	*Million bushels*
1956	3.9	3.2	29.0	94.0
1957	3.1	2.9	36.2	106.0
1958	3.3	3.2	33.3	106.6
1959	3.3	3.2	36.2	114.3
1960	3.3	3.1	32.3	99.9
1961	3.3	3.1	27.2	84.6
1962	3.0	2.7	38.3	104.1
1963	3.2	3.0	35.9	109.6
1964	3.4	3.2	37.5	120.1
1965	3.8	3.4	37.2	126.6
1966	3.5	3.3	37.5	122.4
1967	4.4	4.2	37.3	158.7
1968	4.2	4.0	36.3	146.8
1969	4.0	3.5	38.3	133.6
1970	3.7	3.4	43.4	148.1
1971	3.8	3.7	47.6	174.3
1972	4.2	4.0	46.2	183.5
1973	5.1	4.3	36.1	156.1
1974	5.4	5.1	41.6	213.8
1975	5.6	5.3	50.2	267.2
1976	5.8	5.5	48.2	264.1
1977	5.3	4.9	39.3	191.5
1978	5.1	4.8	46.4	222.8
1979	5.9	5.0	46.1	231.8
1980	6.0	5.7	57.1	323.1
1981	6.0	5.7	61.6	352.8
1982	5.4	5.1	54.7	279.6
1983	5.0	4.5	63.9	284.7
1984	4.9	4.5	64.6	291.1

Source: (*37*).

Appendix table 6—Corn Belt wheat acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	Million acres		*Bushels*	*Million bushels*
1956	6.5	6.1	31.0	189.2
1957	6.6	6.3	22.8	142.8
1958	6.4	6.0	30.7	184.6
1959	6.5	5.8	25.3	147.0
1960	6.0	5.7	31.2	176.9
1961	6.2	5.9	32.6	194.4
1962	5.5	5.1	31.5	159.1
1963	6.2	5.9	37.8	223.2
1964	6.7	6.4	33.5	213.1
1965	6.0	5.2	32.1	166.7
1966	5.2	4.9	39.4	194.4
1967	6.6	6.3	35.5	222.1
1968	5.1	4.8	35.7	171.8
1969	4.5	4.2	36.8	152.7
1970	3.8	3.6	36.6	131.0
1971	3.7	3.4	44.0	151.8
1972	4.3	4.0	44.2	177.3
1973	4.0	3.7	31.4	115.8
1974	6.1	5.8	34.1	198.1
1975	6.8	6.4	39.4	253.2
1976	7.4	6.9	36.9	255.4
1977	6.8	6.2	43.1	268.4
1978	4.0	3.6	37.5	134.4
1979	5.5	5.2	45.3	234.1
1980	6.5	6.2	46.6	288.9
1981	8.3	7.7	45.0	347.6
1982	6.8	6.0	39.8	240.2
1983	6.2	5.5	44.8	244.9
1984	6.7	5.9	43.2	254.7

Source: (*37*).

Appendix table 7—Lake States wheat acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	------- *Million acres* -------		*Bushels*	*Million bushels*
1956	1.9	1.8	27.4	49.9
1957	1.8	1.7	26.3	45.8
1958	2.0	1.9	35.2	68.9
1959	2.3	2.1	27.9	59.7
1960	2.1	2.0	29.7	61.6
1961	2.2	2.2	30.4	66.9
1962	1.7	1.7	29.6	49.8
1963	2.0	2.0	32.0	63.9
1964	2.0	2.0	31.7	63.1
1965	1.8	1.7	30.4	50.8
1966	1.6	1.6	31.3	50.1
1967	2.3	2.2	34.2	76.3
1968	2.0	1.9	34.3	65.3
1969	1.5	1.4	34.0	49.4
1970	1.4	1.4	31.8	43.3
1971	2.1	2.1	45.4	78.7
1972	2.2	2.1	34.7	71.6
1973	2.7	2.6	38.0	98.9
1974	3.8	3.7	31.6	117.7
1975	4.2	3.9	32.5	125.4
1976	5.1	5.0	33.2	166.8
1977	4.4	4.2	39.7	168.0
1978	3.3	3.2	34.4	111.2
1979	3.4	3.3	36.9	124.2
1980	4.6	4.1	34.8	142.1
1981	4.6	4.1	34.8	191.0
1982	4.0	3.9	40.2	155.4
1983	3.3	3.0	40.2	120.5
1984	3.7	3.5	50.0	176.3

Source: (*30*).

Appendix table 8—Rice yields, by State

Crop year	Arkansas	Louisiana	Mississippi	Texas	California
			Pounds		
1956	3,200	2,700	2,850	2,900	4,200
1957	3,100	2,675	3,200	3,200	4,300
1958	2,950	2,650	2,800	3,100	4,450
1959	3,400	2,850	2,700	3,150	4,650
1960	3,525	2,850	2,950	3,075	4,775
1961	3,500	2,925	3,300	2,900	4,800
1962	3,850	3,050	3,200	3,550	4,950
1963	4,300	3,325	3,900	4,125	4,325
1964	4,300	3,300	3,800	4,150	5,050
1965	4,300	3,550	3,700	4,600	4,900
1966	4,300	3,700	4,300	4,200	5,500
1967	4,550	3,900	4,300	5,000	4,900
1968	4,350	3,900	4,300	4,600	5,325
1969	3,950	3,400	4,200	3,950	5,525
1970	4,900	3,900	4,400	4,450	5,700
1971	5.050	3,800	4,600	5,100	5,200
1972	4,975	3,825	4,559	4,727	5,614
1973	4,770	3,451	4,306	3,740	5,616
1974	4,535	3,650	4,180	4,494	5,380
1975	4,770	3,810	3,900	4,560	5,750
1976	4,230	3,910	4,200	4,810	5,520
1977	4,480	3,670	4,000	4,670	5,810
1978	4,485	3,820	4,250	4,700	5,220
1979	4,320	3,910	4,050	4,220	6,520
1980	4,111	3,550	3,840	4,230	6,440
1981	4,520	4,060	4,390	4,700	6,900
1982	4,288	4,160	4,100	4,690	6,700
1983	4,820	3,820	4,000	4,340	7,040
1984	4,600	4,150	4,350	4,940	7,120
1985	5,200	4,370	5,350	5,490	7,400
1986	5,300	4,500	5,400	6,250	7,700

Source: (*34*).

Appendix table 9—Corn acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	Million acres		*Bushels*	*Million bushels*
1956	77.8	64.9	47.4	3,075
1957	73.2	63.1	48.3	3,045
1958	73.4	63.5	52.8	3,356
1959	82.7	72.1	53.1	3,825
1960	81.4	71.4	54.7	3,907
1961	65.9	57.6	62.4	3,598
1962	65.0	55.7	64.7	3,606
1963	68.8	59.2	67.9	4,019
1964	65.8	55.4	62.9	3,484
1965	65.2	55.4	74.1	4,103
1966	66.3	57.0	73.1	4,167
1967	71.2	60.7	80.1	4,860
1968	65.1	56.0	79.5	4,450
1969	64.3	54.6	85.9	4,687
1970	66.9	57.4	72.4	4,152
1971	74.2	64.1	88.1	5,646
1972	67.1	57.5	97.0	5,580
1973	72.3	62.1	91.3	5,671
1974	77.9	65.4	71.9	4,701
1975	78.7	67.6	86.4	5,841
1976	84.6	71.5	88.0	6,289
1977	84.3	71.6	90.8	6,505
1978	81.7	71.9	101.0	7,268
1979	81.4	72.4	109.5	7,928
1980	84.0	73.0	91.0	6,395
1981	84.1	74.5	108.9	8,119
1982	81.9	72.7	113.2	8,235
1983	60.2	51.5	81.1	4,175
1984	80.5	71.9	106.7	7,674
1985	83.4	75.2	118.0	8,877
1986	76.7	69.2	119.3	8,253

Source: (*32*).

Appendix table 10—Corn Belt corn acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	Million acres		*Bushels*	*Million bushels*
1956	31.6	29.6	59.0	1,745
1957	29.8	28.2	59.2	1,668
1958	30.1	28.4	64.5	1,833
1959	35.8	34.5	57.4	1,983
1960	36.4	34.7	64.7	2,247
1961	28.6	27.4	74.9	2,051
1962	29.1	27.5	78.2	2,151
1963	31.5	29.9	80.9	2,416
1964	31.1	29.4	73.7	2,169
1965	32.0	30.4	86.2	2,621
1966	33.0	31.5	82.5	2,600
1967	35.7	33.5	90.5	3,030
1968	32.0	30.4	89.6	2,728
1969	31.5	29.3	96.2	2,823
1970	32.6	30.8	77.5	2,388
1971	35.4	33.8	100.6	3,397
1972	31.9	30.3	107.7	3,263
1973	33.3	31.7	100.8	3,194
1974	36.2	33.6	76.9	2,581
1975	36.9	34.9	97.5	3,403
1976	39.7	37.5	98.1	3,675
1977	38.6	39.1	89.3	3,493
1978	37.8	36.1	97.7	3,530
1979	37.7	36.1	99.7	3,603
1980	38.9	37.0	98.5	3,646
1981	38.3	36.7	120.6	4,420
1982	38.3	36.8	122.8	4,522
1983	27.0	25.4	79.1	2,006
1984	37.1	35.7	112.4	4,012

Source: (*37*).

Appendix table 11—Northern Plains corn acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	------- Million acres -------		Bushels	Million bushels
1956	13.3	8.6	26.0	223
1957	12.0	10.0	39.3	392
1958	12.8	10.6	41.7	443
1959	14.6	11.1	41.6	460
1960	14.5	12.0	45.0	540
1961	11.6	9.4	46.6	440
1962	11.3	9.2	53.4	489
1963	12.0	9.8	52.1	512
1964	10.3	7.6	44.3	337
1965	9.5	7.2	57.3	411
1966	9.9	7.9	64.8	509
1967	10.7	8.1	61.9	503
1968	10.1	7.9	65.7	518
1969	10.3	8.3	80.2	666
1970	11.0	8.7	64.0	556
1971	12.0	9.4	75.0	707
1972	11.0	9.0	92.5	830
1973	12.8	10.3	83.7	865
1974	13.3	9.9	62.4	616
1975	12.5	10.0	73.8	734
1976	12.7	9.3	79.2	736
1977	12.8	10.6	89.8	956
1978	13.0	12.2	91.9	1,117
1979	13.4	11.8	104.3	1,229
1980	13.7	10.9	78.5	853
1981	13.3	11.3	104.4	1,183
1982	13.0	11.2	99.4	1,116
1983	9.6	8.2	84.4	690
1984	12.8	11.2	101.1	1,136

Source: (*37*).

Appendix table 12—Lake States corn acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	------- Million acres -------		Bushels	Million bushels
1956	10.5	8.4	59.0	496
1957	10.5	8.1	57.8	470
1958	10.4	7.8	56.1	437
1959	12.0	9.7	55.7	539
1960	11.8	9.3	55.6	515
1961	10.2	8.1	66.5	538
1962	9.9	7.5	62.3	467
1963	10.5	8.1	68.3	555
1964	10.3	7.5	61.0	457
1965	10.2	7.4	64.3	474
1966	9.7	7.6	77.2	583
1967	10.6	8.0	73.6	591
1968	9.8	7.6	84.4	637
1969	9.2	7.0	85.7	600
1970	9.7	7.8	83.6	653
1971	12.1	9.8	84.1	821
1972	10.8	8.8	91.5	802
1973	11.7	9.5	88.1	834
1974	13.0	10.1	63.6	645
1975	13.2	10.4	75.1	782
1976	13.7	10.2	63.3	643
1977	14.0	11.5	97.8	1,129
1978	13.9	11.6	97.7	1,132
1979	13.9	11.6	99.7	1,161
1980	14.4	12.2	98.5	1,206
1981	15.4	13.1	106.4	1,396
1982	14.9	12.6	110.4	1,390
1983	10.5	8.5	89.2	756
1984	14.5	12.3	101.8	1,254

Source: (*37*).

Appendix table 13—Sorghum acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	Million acres	*Million acres*	*Bushels*	*Million bushels*
1956	21.4	9.2	22.2	205
1957	26.9	19.7	28.8	568
1958	20.7	16.5	35.2	581
1959	19.6	15.4	36.1	555
1960	19.6	15.6	39.7	620
1961	14.3	11.0	43.7	480
1962	15.1	11.6	44.1	510
1963	17.5	13.3	43.9	585
1964	16.8	11.7	41.7	490
1965	17.1	13.0	51.6	672
1966	16.4	12.8	55.8	715
1967	18.9	15.0	50.4	755
1968	17.8	13.9	52.6	731
1969	17.2	13.4	54.3	730
1970	17.0	13.6	50.4	683
1971	20.5	16.1	53.8	868
1972	17.0	13.2	60.7	801
1973	19.0	15.7	58.8	923
1974	17.6	13.8	45.1	623
1975	18.1	15.4	49.0	754
1976	18.1	14.5	49.1	711
1977	16.1	13.8	56.6	781
1978	16.2	13.4	54.5	731
1979	15.3	12.9	62.6	807
1980	15.6	12.5	46.3	579
1981	15.9	13.7	64.0	876
1982	16.0	14.1	59.1	835
1983	11.9	10.0	48.7	488
1984	17.3	15.4	56.4	866
1985	18.3	16.7	66.8	1,113
1986	15.3	13.9	67.7	942

Source: (*35*).

Appendix table 14—Southern Plains sorghum acreage, yield, and production

Crop year	Harvested	Yield	Production
	Million acres	*Bushels*	*Million bushels*
1956	5.4	24.4	131
1957	8.4	30.8	260
1958	8.3	32.4	270
1959	7.9	35.2	277
1960	7.6	37.2	282
1961	5.7	43.6	247
1962	5.8	38.0	221
1963	6.3	42.3	265
1964	5.3	43.8	230
1965	5.8	54.1	316
1966	6.1	54.7	332
1967	7.4	49.8	369
1968	6.8	53.6	367
1969	6.7	49.8	336
1970	6.4	54.9	353
1971	6.6	50.2	330
1972	6.1	57.3	347
1973	7.6	58.5	447
1974	6.6	50.7	335
1975	7.7	51.1	395
1976	6.4	48.7	310
1977	5.4	46.9	252
1978	5.1	47.8	246
1979	5.0	53.1	266
1980	4.4	44.7	198
1981	4.9	59.9	296
1982	6.1	53.7	325
1983	3.5	48.3	169
1984	4.4	51.7	227

Source: (*37*).

Appendix table 15—Northern Plains sorghum acreage, yield, and production

Crop year	Harvested	Yield	Production
	Million acres	*Bushels*	*Million bushels*
1956	2.6	14.7	39
1957	8.4	25.5	213
1958	5.7	37.1	213
1959	5.6	36.8	207
1960	6.3	42.3	265
1961	4.1	42.8	176
1962	4.6	50.9	235
1963	5.9	44.4	261
1964	5.2	37.7	197
1965	5.7	47.8	273
1966	5.2	56.1	294
1967	5.8	48.8	281
1968	5.4	49.9	270
1969	5.0	61.7	311
1970	5.3	43.5	233
1971	6.7	54.8	369
1972	5.4	64.3	349
1973	6.2	59.3	365
1974	5.5	36.9	201
1975	5.6	45.7	255
1976	6.2	47.3	293
1977	6.5	62.9	407
1978	6.1	58.3	355
1979	5.8	70.9	414
1980	5.8	48.4	282
1981	6.1	69.6	423
1982	5.5	64.4	353
1983	4.0	49.2	196
1984	6.5	54.5	357

Source: (*37*).

Appendix table 16—Corn Belt sorghum acreage, yield, and production

Crop year	Harvested	Yield	Production
	Thousand acres	*Bushels*	*Million bushels*
1956	278	34.6	10
1957	941	44.8	42
1958	934	52.4	49
1959	598	50.5	30
1960	533	46.4	25
1961	244	48.4	12
1962	206	47.3	10
1963	222	53.7	12
1964	242	51.5	13
1965	283	62.0	18
1966	258	58.2	15
1967	306	58.9	18
1968	277	66.2	18
1969	267	66.4	18
1970	296	55.8	17
1971	929	76.6	71
1972	505	71.4	36
1973	547	69.2	38
1974	549	50.4	28
1975	634	55.1	35
1976	774	60.3	47
1977	1,041	72.5	76
1978	952	77.0	73
1979	820	80.2	66
1980	949	49.2	47
1981	1,060	78.4	83
1982	969	76.8	74
1983	788	60.0	47
1984	1,640	68.9	113

Source: (*37*).

Appendix table 17—Barley acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	Million acres		Bushels	Million bushels
1956	14.7	12.9	29.3	377
1957	16.4	14.9	29.8	443
1958	16.1	14.8	32.3	477
1959	16.8	14.9	28.3	420
1960	15.5	13.9	31.0	429
1961	15.6	12.8	30.6	392
1962	14.4	12.2	35.0	428
1963	13.5	11.2	35.0	393
1964	11.7	10.3	37.6	386
1965	10.1	9.2	42.9	393
1966	11.2	10.3	38.3	392
1967	10.1	9.2	40.5	374
1968	10.5	9.7	43.8	426
1969	10.3	9.6	44.7	427
1970	10.5	9.7	42.8	416
1971	11.1	10.1	45.8	463
1972	10.6	9.6	43.7	422
1973	11.0	10.3	40.5	417
1974	8.7	7.9	37.7	299
1975	9.4	8.6	44.0	379
1976	9.3	8.4	45.4	383
1977	10.8	9.7	44.0	428
1978	10.0	9.2	49.2	455
1979	8.1	7.5	50.9	383
1980	8.3	7.3	49.7	361
1981	9.6	9.0	52.4	474
1982	9.5	9.0	57.2	516
1983	10.4	9.7	52.3	508
1984	11.9	11.2	53.4	599
1985	13.2	11.6	51.0	591
1986	13.1	12.0	50.8	610

Source: (*31*).

Appendix table 18—Northern Plains barley acreage, yield, and production

Crop year	Harvested	Yield	Production
	Million acres	Bushels	Million bushels
1956	4.3	21.8	94
1957	5.0	22.5	112
1958	5.3	28.1	150
1959	5.4	20.6	112
1960	4.9	25.5	125
1961	3.9	22.7	90
1962	4.1	31.8	131
1963	4.0	28.8	116
1964	3.4	29.9	102
1965	2.8	39.1	111
1966	3.4	30.2	102
1967	3.1	33.2	102
1968	3.3	40.4	131
1969	2.7	40.7	111
1970	2.6	32.8	87
1971	2.9	44.1	129
1972	3.3	39.4	131
1973	3.5	36.8	129
1974	2.6	27.6	72
1975	2.7	36.6	99
1976	2.6	35.1	91
1977	3.3	39.6	130
1978	3.1	44.2	137
1979	2.3	44.5	100
1980	2.0	32.5	66
1981	2.9	44.6	128
1982	2.7	50.6	135
1983	3.4	45.3	155
1984	3.7	51.8	193

Source: (*37*).

Appendix table 19—Lake States barley acreage, yield, and production

Crop year	Harvested	Yield	Production
	Million acres	*Bushels*	*Million bushels*
1956	1.14	29.6	33.8
1957	.96	26.3	25.1
1958	.99	37.1	36.8
1959	1.13	29.5	33.2
1960	1.00	32.8	32.6
1961	1.01	30.8	31.0
1962	.81	26.8	21.7
1963	.79	36.4	28.8
1964	.67	33.2	22.2
1965	.64	44.1	28.1
1966	.71	32.8	23.2
1967	.82	46.9	38.4
1968	1.07	47.6	50.7
1969	.74	45.4	33.4
1970	.63	38.5	24.3
1971	.89	48.6	43.3
1972	.83	43.3	36.1
1973	.94	45.6	42.7
1974	.78	39.4	30.6
1975	.86	38.4	32.9
1976	.91	41.1	37.4
1977	1.13	51.1	57.6
1978	1.10	49.4	54.3
1979	.81	52.9	43.1
1980	.86	43.3	37.3
1981	1.09	55.7	60.6
1982	.95	57.9	55.0
1983	.85	52.5	44.5
1984	1.03	64.3	66.4

Source: (*37*).

Appendix table 20—Pacific States barley acreage, yield, and production

Crop year	Harvested	Yield	Production
	Million acres	*Bushels*	*Million bushels*
1956	3.0	36.7	112
1957	3.4	39.4	133
1958	3.1	34.9	110
1959	3.0	38.3	115
1960	2.7	42.0	114
1961	2.7	43.5	119
1962	2.5	48.5	121
1963	2.5	45.2	113
1964	2.2	51.4	114
1965	2.1	49.6	103
1966	2.1	48.7	103
1967	1.9	48.2	94
1968	1.9	45.7	89
1969	1.8	46.3	85
1970	1.9	49.9	97
1971	1.8	53.9	99
1972	1.4	53.8	77
1973	1.5	47.1	71
1974	1.3	49.8	67
1975	1.6	55.2	89
1976	1.6	54.5	85
1977	1.5	48.0	72
1978	1.5	52.0	80
1979	1.3	57.5	73
1980	1.3	66.7	87
1981	1.6	60.2	96
1982	1.7	61.5	102
1983	1.6	62.6	100
1984	1.7	64.0	110

Source: (*37*).

Appendix table 21—Mountain States barley acreage, yield, and production

Crop year	Harvested	Yield	Production
	Million acres	*Bushels*	*Million bushels*
1956	2.3	32.3	75
1957	3.4	31.8	109
1958	3.1	33.7	104
1959	3.5	30.1	104
1960	3.3	28.8	94
1961	3.0	27.1	82
1962	2.9	37.6	110
1963	2.9	33.7	98
1964	2.9	35.1	101
1965	2.5	44.1	111
1966	2.9	41.2	118
1967	2.4	41.5	101
1968	2.4	45.9	108
1969	3.0	47.3	141
1970	3.2	46.4	148
1971	3.2	44.4	140
1972	3.1	45.1	138
1973	3.5	40.1	140
1974	2.5	39.2	99
1975	2.7	46.5	123
1976	2.6	50.7	131
1977	3.0	44.2	130
1978	2.9	53.8	158
1979	2.6	53.1	140
1980	2.6	57.5	148
1981	3.1	54.0	166
1982	3.3	61.1	202
1983	3.5	54.1	192
1984	4.2	47.5	200

Source: (*37*).

Appendix table 22—Oats acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	------- *Million acres*	-------	*Bushels*	*Million bushels*
1956	44.2	33.3	34.5	1,151
1957	41.8	34.1	37.9	1,290
1958	37.7	31.2	44.8	1,401
1959	35.1	27.8	37.8	1,050
1960	31.4	26.6	43.4	1,153
1961	32.3	23.9	42.3	1,010
1962	29.5	22.4	45.2	1,012
1963	28.1	21.3	45.3	966
1964	25.6	19.8	43.1	852
1965	24.0	18.5	50.2	930
1966	23.3	17.9	44.9	803
1967	20.7	16.1	49.3	794
1968	23.3	17.7	53.7	951
1969	23.6	18.0	53.7	966
1970	24.4	18.6	49.2	915
1971	21.8	15.7	55.9	878
1972	20.0	13.4	51.5	691
1973	18.6	13.8	47.9	659
1974	17.0	12.6	47.6	601
1975	16.4	13.0	49.0	639
1976	16.6	11.8	45.7	540
1977	17.7	13.5	55.8	753
1978	16.4	11.1	52.3	582
1979	14.0	9.7	54.4	527
1980	13.4	8.7	53.0	458
1981	13.7	9.4	54.1	509
1982	14.3	10.6	58.4	593
1983	20.3	9.1	52.6	477
1984	12.4	8.1	58.0	474
1985	13.3	8.2	63.7	521
1986	14.7	6.9	56.0	385

Source: (*33*).

Appendix table 23—Corn Belt oats acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	------- Million acres -------		Bushels	Million bushels
1956	13.8	11.7	37.8	442
1957	12.2	10.9	39.2	427
1958	11.1	9.9	48.2	477
1959	10.0	9.1	41.4	377
1960	8.8	8.3	47.9	398
1961	9.3	6.7	46.8	314
1962	8.2	6.2	48.1	298
1963	7.4	5.8	51.8	300
1964	6.5	4.8	48.8	234
1965	5.7	4.0	53.4	214
1966	5.6	4.1	53.9	221
1967	4.7	3.6	53.3	192
1968	5.7	3.9	61.6	240
1969	5.3	3.6	55.1	198
1970	4.9	3.4	54.9	187
1971	4.8	3.2	60.2	193
1972	4.6	2.4	58.3	140
1973	3.4	2.5	49.4	124
1974	3.2	2.6	54.8	143
1975	3.2	2.6	55.0	143
1976	3.1	2.5	57.1	143
1977	2.8	2.3	59.6	137
1978	3.0	1.8	57.7	104
1979	2.2	1.7	63.1	107
1980	2.1	1.7	62.4	106
1981	2.1	1.6	62.2	100
1982	2.3	1.7	58.9	100
1983	8.1	1.3	55.0	74
1984	2.1	1.2	62.9	78

Source: (*37*).

Appendix table 24—Lake States oats acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	------- Million acres -------		Bushels	Million bushels
1956	8.4	8.0	40.7	326
1957	8.0	7.6	46.1	350
1958	7.7	7.4	56.0	414
1959	7.4	7.1	46.8	332
1960	6.9	6.8	48.6	331
1961	7.1	6.6	49.5	327
1962	6.3	6.0	50.5	303
1963	6.5	6.2	52.3	324
1964	6.1	5.8	48.3	280
1965	5.8	5.5	56.5	311
1966	5.8	5.4	48.5	262
1967	5.4	5.1	56.6	289
1968	6.1	5.6	60.3	338
1969	5.7	5.5	58.9	324
1970	5.8	5.5	54.7	301
1971	5.1	5.0	58.9	295
1972	4.5	4.1	53.2	218
1973	4.5	4.3	51.3	221
1974	4.0	3.8	54.6	208
1975	4.0	3.7	53.5	198
1976	4.2	3.7	45.5	168
1977	4.2	3.9	66.0	257
1978	3.8	3.4	55.0	187
1979	3.1	2.8	57.5	161
1980	3.1	2.7	58.8	159
1981	3.1	2.7	61.2	165
1982	3.5	3.0	61.2	184
1983	4.2	2.5	55.0	132
1984	2.9	2.4	64.2	153

Source: (*37*).

Appendix table 25—Northern Plains oats acreage, yield, and production

Crop year	Planted	Harvested	Yield	Production
	Million acres		*Bushels*	*Million bushels*
1956	9.2	6.4	21.0	134
1957	8.3	7.6	33.4	254
1958	7.5	7.0	37.2	260
1959	7.3	5.7	22.9	131
1960	6.8	6.3	37.1	234
1961	6.9	5.4	31.1	168
1962	6.4	5.8	41.9	243
1963	6.2	5.6	34.4	193
1964	6.0	5.4	33.8	183
1965	5.7	5.3	47.4	251
1966	5.7	5.0	36.7	184
1967	5.3	4.8	42.2	203
1968	5.8	5.2	44.9	234
1969	6.4	5.8	50.8	295
1970	6.6	6.0	42.1	253
1971	5.6	5.1	53.8	274
1972	5.2	4.6	49.7	229
1973	5.3	4.5	44.6	201
1974	5.0	4.2	37.3	157
1975	4.9	4.3	43.6	188
1976	5.0	3.5	35.7	125
1977	6.1	5.0	50.0	250
1978	4.6	3.8	48.7	185
1979	4.0	3.2	48.7	156
1980	4.0	2.5	40.7	102
1981	4.3	3.2	43.9	141
1982	4.5	4.0	57.5	230
1983	4.1	3.4	48.6	165
1984	3.5	3.0	53.6	158

Source: (*37*).

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